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ARMOR SYSTEMS DEVELOPMENT/EVALUATION GUIDELINE

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FOREWORD

This guideline is the culmination of an extensive program involving the work of many people within the Laboratories. It is important to note the contributions of those listed below.

S. Moreland	Initial Program Formulation
M. G. Golden	Guideline Development & Coordination
J. H. Sullivan J. A. Schaefer D. T. Gantz	Mathematical Analysis & Treatments
G. T. Thomas D. W. Haugen	Crew Activity Analysis & Mission Planning
W. T. Nemeth	Photographic Assistance
C. F. Sohn	Model Fabrication

ABSTRACT

This guide was developed to establish a systematic approach to the design of aircrew armor systems. It provides an integrated investigation of the feasibility of adding armor to an aircraft based on the aircraft's systems, mission and performance requirements; and the assessment of the aircrew's "protection need" based on the aircraft's mission, environment, required aircrew functions, and inherent ballistic protection provided the crew by the aircraft components.

The data derived from these analyses are synthesized into an Armor Design/Evaluation Methodology which utilizes a complex computer-graphics technique as a design tool. To illustrate this computer technique, several sample armor configurations modeled on the UH-1C aircraft are developed and evaluated. The effectiveness of this method, however, depends upon the accuracy of the input data generated and upon the application of human factors design principles.

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ARMOR SYSTEMS DEVELOPMENT/EVALUATION GUIDELINE

INTRODUCTION

This is the final report of an effort to develop a method for designing and evaluating aircrew armor systems. The study was conducted by the Aviation Branch, Systems Research Laboratory, of the U. S. Army Human Engineering Laboratories (HEL) for the U. S. Army Natick Laboratories under NLABS Project Ord. Nos. 67-83 and 68-147, Task 01 of DA Project No. 1-F-141-812-D154.

For clarity, the introductory section presents an overview of the entire guideline and briefly outlines and summarizes the various steps involved in each phase.

Throughout the report a concerted effort has been made to emphasize methods and procedures in direct proportion to their contribution to the overall methodology. In addition, wherever possible, dependence of the various analytic techniques upon empirical data has been underscored.

The Army airmobile concept employing organic Army aircraft in Vietnam dictates a requirement for responsive aircraft support during combat operations. To achieve this requirement, Army helicopters often operate at low altitudes where they are subject to concentrated enemy groundfire. Mission success and aircraft/crew survival can be enhanced through the effective use of aircraft and aircrew protective armor.

As a result of the urgent need for aircrew armor in Vietnam, past development efforts to utilize aircrew body, seat and aircraft armor have been made independently, with no attempt to combine the armor into an integrated system. Few analytical methods were initially employed to investigate mission-related crew tasks/motions, crew protection needs, etc. Prototype tests occurred so late in the development program that any needed redesign indicated by them was usually costly, since designs were frozen by then and manufacturing commitments made. Consequently, the final armor configuration overprotected some areas while leaving others completely unprotected.

Because of differing aircraft system requirements and varying levels of aircraft/crew station subsystem development, many techniques and procedures are currently applied by manufacturers when developing advanced aircrew armor systems. Since the Army procuring activity must review the crew stations/armor configuration prior to prototype flight, they must understand in detail the idiosyncrasies unique to

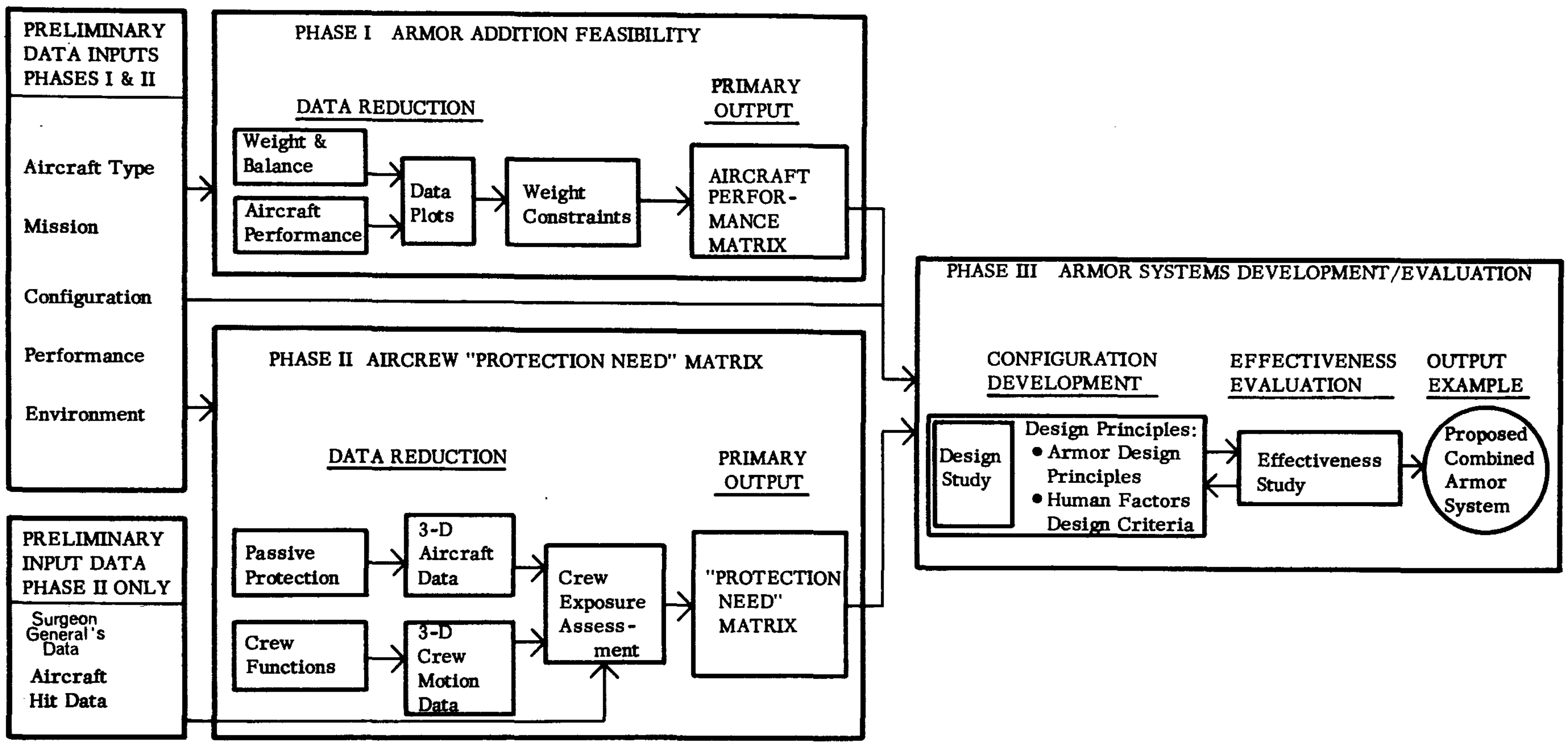


Fig. 1. ARMOR SYSTEMS DEVELOPMENT GUIDELINE

the manufacturers' development techniques and they must make expensive commitments based on the limited output of present evaluation procedures. These difficulties limit the effectiveness of the procuring activity with respect both to specifying armor requirements and evaluating contractor proposals. Much would be gained if standardized methods were established for accurate development and evaluation of aircrew armor systems.

The objective of this study was to develop a method for the design and evaluation of armor systems for both existing and proposed aircraft. It was important that an existing Army combat aircraft system be analyzed to establish the baseline data necessary to the Guideline development. The UH-1 aircraft system was chosen for the study and will be used to illustrate the methods and procedures exercised in the Guideline.

As shown in Figure 1, the general approach involves three phases:

a. Phase I - Armor Addition Feasibility

b. Phase II - Aircrew "Protection Need" Assessment

c. Phase III - Integrated Armor Systems Development/Evaluation

Depending upon the status of the aircraft being developed; e.g., existing or proposed, utilization of the basic armor development guideline would be as follows:

Existing Aircraft	Proposed Aircraft
Phase I	Not required
Phase II	Phase II
Phase III	Phase III

Phase I - Armor Addition Feasibility

When an armor system is to be developed for an existing aircraft, that aircraft's projected mission, configuration, performance and operating environment must first be analyzed to determine:

a. The feasibility of adding additional armor weight to the aircraft system.

b. Armor weight/location combinations, if additions are possible.

c. The aircraft performance changes related to each armor weight/ location combination.

The primary output of this first phase is an aircraft performance matrix. This matrix is represented by a table that indicates whether or not the aircraft can tolerate sufficient armor material to be of consequence and, if so, lists the weight/location combinations tolerable with the associated performance changes.

Phase I of the guideline is not used when generating an armor system for a proposed aircraft since the requirement for aircrew armor protection is written into the proposed aircraft's QMR and RFP documents. In this case, a specific amount of the aircraft's system weight has already been allocated to aircrew armor in the initial weight and balance studies. For proposed aircraft, the armor systems development would begin with Phase II.

Phase II - Aircrew "Protection Need" Assessment

This phase of the guideline presents a method for assessing the aircrew's "protection need" within the total system. This assessment is based primarily on the components offering passive protection and the location of the crew in relation to these components. Implementation of this phase of the guideline is dependent upon the status of the system being studied (existing/proposed).

With an existing aircraft, this phase can be initiated immediately, since the problems entailed in establishing the components/crew locations are few. The aircraft type's mission profile and performance requirements are analyzed (as in Phase I). Mission-related subsystems indicated (weapons, avionics, etc.) are then added to the basic existing aircraft to produce the final mission configuration. The exact crew-station geometry which dictates the crew installation can be readily ascertained from actual measurements or from aircraft inboard profile drawings.

With a proposed aircraft, the total system has yet to be defined. In this case, the guideline cannot be used until the basic component configuration and crew-station geometry have been developed. Once these elements are completed, however, the guideline should be implemented as soon as possible, preferably during the early phases of contract definition.

The primary output of this second phase is the aircrew "protection need" matrix. This matrix is a series of tables which indicates each aircrewman's "protection need" within the aircraft system.

Phase III - Integrated Armor System Development/Evaluation Methodology

This phase of the guideline is divided into three sections as follows:

Section 1, Configuration Development

Working within the armor weight limits, several configurations can be generated to cover the "protection need" as enumerated in the "Protection Need" Matrix (Guideline Phase II). For existing aircraft these weight limits are determined by the Performance Matrix (Guideline Phase I), while for proposed aircraft they are a function of contractor weight and balance studies.

Section 2, Effectiveness Evaluation

If several armor configurations are developed, the effects of each configuration on the crew/aircraft performance can be evaluated according to the following system parameters:

a. Change in amount of crew protection.

b. Change in the aircraft systems weight.

c. Change in the aircrew's field of vision from standard (MIL-STD-850A).

d. Change in the aircrew's motion envelopes.

Section 3, Output Example

Subsequent to the effectiveness evaluation, that configuration best satisfying the "protection need" by producing the smallest amount of change in system weight, crew vision and crew motion envelopes while inducing the largest positive change in crew protection can be proposed as an output example of an optimum integrated armor system.

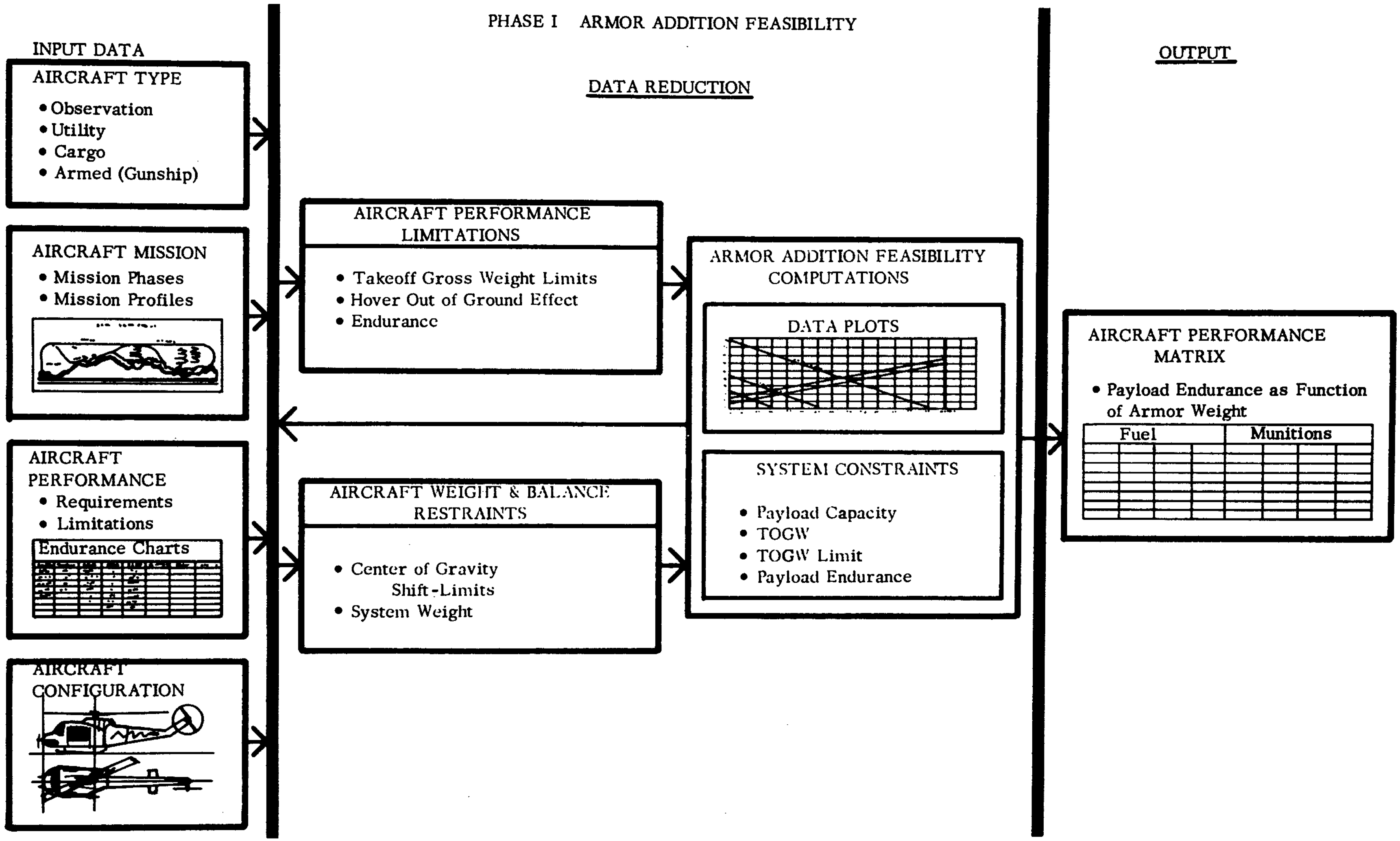


Fig. 2. PHASE I -- FLOW CHART

PHASE I - ARMOR ADDITION FEASIBILITY (Existing Aircraft Only)

PURPOSE

In existing aircraft the various subsystem configurations, including avionics, engines, transmissions, fuel cells, weapon systems, etc., which determine the system's weight, have already been established with little chance of major systems modifications. In this case, aircrew armor is applied in kit form where the armor weight is being added to the aircraft's established weight. Since the aircraft's performance limitations have been computed on the basis of weight relative to the lifting capabilities of the engine/rotor system, the added armor weight must not cause the system's total weight to exceed that limit indicated by the established performance limitation. Therefore, the purpose of this phase of the study is to generate an aircraft performance matrix which indicates the various armor-kit weight/location combinations that an existing aircraft can tolerate with their associated performance changes.

INPUT DATA

As seen in the flow diagram (Fig. 2), the input data necessary to determine added armor kit weight are:

a. Aircraft type.

b. Aircraft mission profile.

c. Aircraft performance requirements.

d. Aircraft configuration.

Aircraft Type

Since aircraft are classified according to their mission, Army fixed and rotary-wing aircraft may be categorized as to the following mission types:

a. Observation.

Observation aircraft are used to conduct visual, photographic or electronic observation and to adjust fires or aerial wire laying. Observation aircraft can also be used for command and control, liaison, reconnaissance, surveillance, and a limited amount of resupply, evacuation and aerial fire support.

b. Utility.

Utility aircraft are used for missions such as cargo and passenger transport, patient movement, unit tactical transport, command and control, and dissemination of material during psychological operations. Armed utility aircraft can be used to escort troop-carrying helicopters and to provide supplementary aerial fire support.

c. Cargo.

Cargo aircraft are used for airmobile operations and for transport of troops, equipment and supplies within the battle area.

d. Armed Helicopter (Gunships).

The primary role of armed helicopters is to provide offensive and defensive fire support during airmobile operations (i.e., reconnaissance escort, delaying actions, patrol actions, area security).

If the existing aircraft lends itself to a variety of missions, the most demanding type should be selected for detailed analysis, since it will generate the most critical set of aircraft requirements, mission tasks and task performance tolerances.

Example:

In formulating the methodology, the UH-1 series of aricraft was selected as a model for the study as it is currently the Army's "work horse" in Vietnam. Of this series, the armed UH-1C helicopter was chosen since its mission type developed the most demanding requirements for aircrew armor.

Aircraft Mission Profile

With the aircraft's specific mission type established, a profile is evolved which defines the variety of missions that the aircraft will be required to perform during normal operations. This profile establishes the aircraft's overall operational requirements such as: primary mission duration, payload configuration, distance traveled, and power/time (endurance) profiles. The mission profile is constructed by analyzing the following data:

a. Threat (Conflict Intensity). The enemy capability of employing forces and firepower to counter the employment of Army aircraft is of vital importance to the aircraft mission. The factors to be considered are:

(1) Number and type of enemy weapons.

(2) Characteristics of enemy weapons; e.g., range, target acquisition means, rate of fire, mobility, elevation limits, and relative effectiveness against aircraft.

b. Airmobile concept employed to counter enemy threat; i.e., current armed-helicopter doctrine, employment tactics for air cavalry troops, etc.

c. Aircraft's operating environment; i.e., terrain, climate, etc.

Analysis of this data will establish the major mission categories for the specific aircraft type selected.

The UH-1C armed helicopter operational missions with their required mission phases are shown in Table 1.

These three basic operating missions with their associated tasks and/or phases are developed from current Army field manuals (Department of the Army, 1963, 1965, 1966a, 1966b), USACDC mission tactics and examination of field reports by the U. S. Army Ballistics Research Laboratories (BRL). The same source material also contains important data which is used to generate a preliminary mission profile such as in Figure 3.

Since the phases that make up the aircraft's operational missions have certain similarities in flight regime, it is possible to eliminate redundant phases and express those remaining in terms of flight modes, as in Table 2.

A final composite mission profile (Fig. 4) is then generated in a manner similar to that used to develop the preliminary profile (e.g., Army field manuals, USABRL data, etc.).

TABLE 1

UH-1C Armed Helicopter

Characteristic Missions and Mission Phases

<u>Fire Support</u>

Takeoff
Transit friendly area
Transit hostile area
Approach assigned target
Delivery of supporting fires
Transit friendly area
Landing

<u>Escort</u>

Takeoff
Interception of column
Escort of column
Security of loading operation
Escort to objective
Delivery of supporting fires
Objective security
Escort of column
Transit of column
Landing

<u>Reconnaissance and Security</u>

Takeoff
Transit friendly area
Reconnaissance
Approach target
Attack assigned target
Reconnaissance
Transit friendly area
Landing

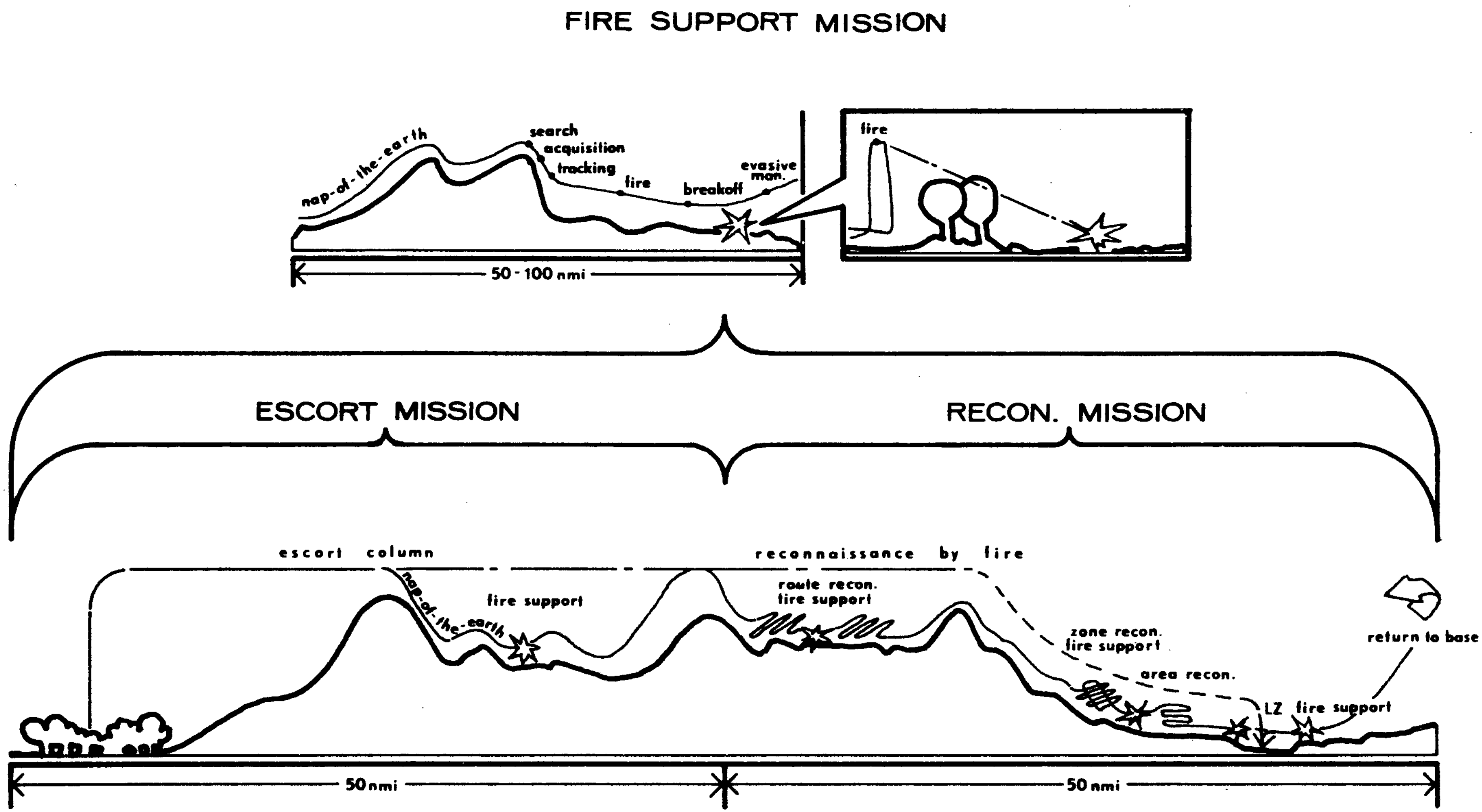


Fig. 3. PRELIMINARY MISSION PROFILE/UH-1C ARMED HELICOPTER

TABLE 2

UH-1C Armed Helicopter Composite Mission

Common Mission Phases

Phase		Flight Mode
Takeoff	-	Hover
Transit friendly area	]	Cruise
Transit hostile area	]	Cruise
Approach target	]	Dash
Attack assigned target	]	Dash
Interception of column	]	Dash
Escort of column	]	Cruise
Security of loading	]	Cruise
Escort to objective	]	Cruise
Delivery of fire	-	Dash
Objective security	-	Loiter
Depart column	]	Cruise
Reconnaissance	]	Cruise
Land	-	Hover

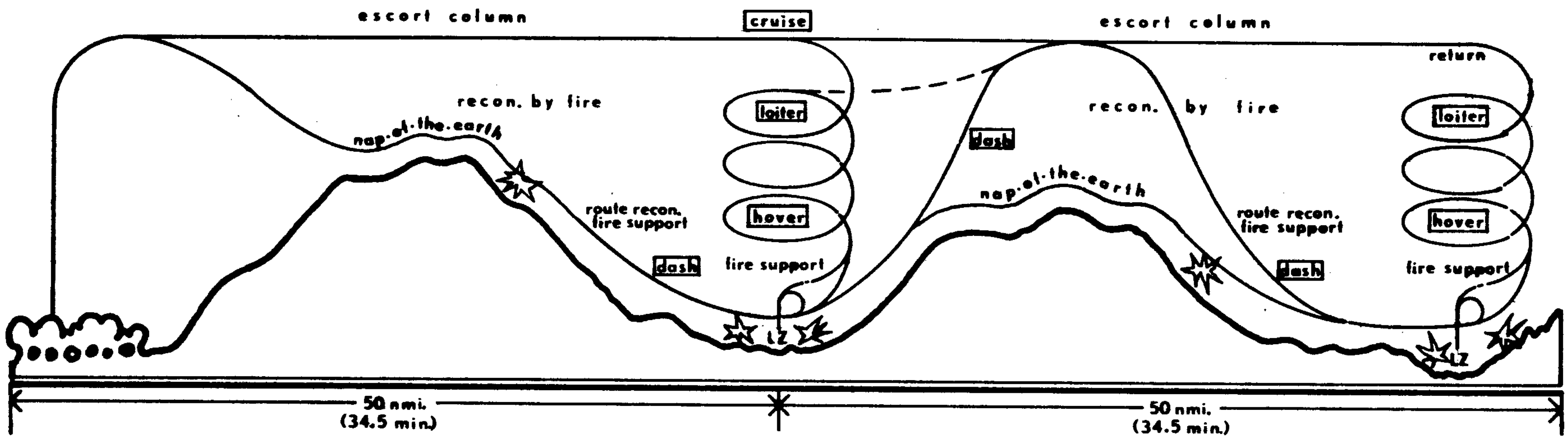


Fig. 4. MISSION PROFILE COMPOSITE/UH-1C ARMED HELICOPTER

Aircraft Performance Requirements

The ratio of aircraft weight to payload weight follows a fairly restricted pattern. Any armor weight which is added to the aircraft will have a definite effect on the aircraft's vertical flight performance, airspeed, potential payload and flight endurance. This dictates the need to analyze the mission profile and establish the desired performance requirements so that when additional armor weight is added to the system, the aircraft will still be capable of performing its particular mission profile. Analysis of the established mission profile will determine the performance requirements as follows:

a. Vertical Flight Performance.

The hover capability is a prime requirement since all forms of deception, cover, dispersion and concealment, and all types of movement are vital to the survival of the helicopter. This requirement will dictate a hover capability, out of ground effects (OGE) under the particular wind velocity, pressure altitude and temperature conditions of the operating environment.

b. Airspeed.

The necessity for selecting a specific speed range stems from the mission requirement to provide quick support to forward troop elements. Also, the specific airspeed will have a definite effect on the aircraft's overall endurance.

c. Endurance.

This factor stems from the mission requirement of the aircraft to support forward troop elements and operate in the area long enough to be effective. Analyzing the mission profile determines the mission duration, distance traveled and the power/time profiles which are then used to project an endurance chart (Table 3).

TABLE 3

Endurance Chart

UH-1C Armed Helicopter

Flight Modes From Mission Profiles	Percent of Specified Endurance From Profile
Hover (OGE)	20%
Dash	15% (120K)
Loiter	5% (60K)
Cruise	50% (80K)
Reserve (Min)	10%

Aircraft Endurance Maximum Fuel Load $\frac{\text{1573 lbs.}}{\text{450 hrs.}}$ /3.5 hrs.

Mission Specified Endurance:

Flight Time (1.8 hrs./incl 30 min. reserve)
Distance Traveled (100 nmi)

Hover Power Settings (OGE) -- Representative of takeoff climb-out, flight-path control in approach and landings.

Dash Mode -- Represents flight-path acceleration at maximum permissible airspeed settings so as to minimize exposure during target attack and delivery of fire.

Loiter -- Flight at best endurance speed.

Cruise Mode -- Covers normal en route operations such as escort, reconnaissance, etc.

Aircraft Mission Configuration

An analysis of current airmobile concepts for the aircraft type and the desired performance requirements from the mission profile will indicate the aircraft's mission configuration. This will include the number of crewmen, avionics, weapon systems applicable and the minimum amount of fuel and ammunition necessary to complete the mission profile.

Example:

Current field manuals and present Vietnam employment tactics (U. S. Army Ballistics Research Laboratories, U. S. Army Limited War Laboratory) were reviewed to establish a mission configuration for the UH-1C study aircraft in a gunship role; i.e., to determine dominant armament system, typical gunship sortee, etc. The breakdown for the study aircraft follows:

Basic Aircraft: UH-1C

Crew: Pilot/Copilot

Fuel: (from Endurance Chart, Table 3)

Preflight Warmup	10.0 min.
Sortee (1)	34.5 min.
Sortee (2)	34.5 min.
Reserve (Emergency)	30.0 min.
Total	109.0 min. = 1.8 hrs.

Consumption Rate: $\frac{450 \text{ gal.}}{\text{hr.}}$ 817 lbs.

Weapon System: XM-21 Helicopter Armament Subsystem

Armament: Two 7.62mm, XM134 Dual high-rate machine guns
Two XM 157 rocket pods

Ammunition capacity: 6000 rds of 7.62mm Cartridges
14 - 2.75" FFAR Rockets

Weight: Complete subsystem less ammunition (approx) -- 543 lbs.

6000 rds of 7.62mm ammo (linked 4 ball, 1 tracer) -- 390 lbs.

14 rockets with XM151 warhead and WM423 fuze -- 287 lbs.

PERFORMANCE MATRIX DEVELOPMENT

With the aircraft's desired configuration and performance requirements established, the amount of armor-kit weight that may be added to the existing system is determined through gross weight and center of gravity (CG) computations.

Definition of Variables

Throughout these computations certain terminology is used. For purposes of clarity, the following definitions from the UH-1C operator's manual (Department of the Army, 1968c) are given:

Basic Weight: The basic weight of the aircraft is the weight which includes all fixed operating equipment and trapped fuel and oil.

Operating Weight: The operating weight of the aircraft is the basic weight plus those variable items which remain substantially constant for the aircraft type/mission. These include oil, crew, baggage, and emergency and extra equipment that may be required (e.g., weapons, supports, etc.), excluding fuel and payload.

Gross Weight: The gross weight is the total weight of the aircraft plus its contents as follows:

> Takeoff gross weight is the operating weight plus the variable and expendable load items which may vary with the mission. These items include fuel, cargo, passengers, ammunition, etc.
>
> The landing gross weight is the takeoff gross weight minus the expended load items.

Reference Datum: Reference datum is an imaginary vertical plane on the helicopter from which all horizontal distances are measured for balance purposes. This datum is usually located at or near the nose of the craft to coincide with structural station zero. When this datum is used, the arm of any item loaded corresponds to the structural station number over which the CG of the item is placed.

Arm: For balance purposes, arm is the horizontal distance in inches from the reference datum to the CG of a given item.

Moment: Moment is the weight of an item multiplied by its arm.

Total Moment: The total moment is the sum of the moments of all items making up the aircraft weight with respect to the reference datum.

Center of Gravity (CG): The center of gravity is a point about which a helicopter would balance if suspended. Its distance from the reference datum is found by dividing the total moment by the gross weight of the aircraft. To find the CG of an individual item at a specific location, divide the moment of the item by its weight.

CG Limits: CG limits are the extremes of movement which the CG can have without making the helicopter unsafe to fly.

Maximum Endurance (including reserve): This variable refers to the maximum available flight time related to the fuel quantity and gross weight conditions of the aircraft at various altitudes and airspeeds.

Pressure Altitude: This variable is the altitude above standard sea level (29.92 in hg.) measured with a barometric altimeter.

Weights and Balances Equations

When determining the aircraft's mission configuration, calculations must be made to insure that the system's established weight and balance limitations are not exceeded. A weight and moments table (Table 4) is constructed where, based on the mission profile, the aircraft's configuration at basic weight, operating weight and takeoff gross weight is tabulated using the aircraft's inboard profile drawings and the operator's manual. As each weight is indexed (basic, operating, takeoff), the aircraft's balance must be maintained. This balance or center of gravity is located in an area which has definite fore and aft shift limits. To hold the system's CG within these limits, a relationship must exist between the weights and distances on each side of the CG. The proper relationship is determined in moments.

The total moment exerted on the system is defined as the sums of the individual moments (M), symbolically expressed:

$$\text{Total Moment of System, } M_S = M_1 + M_2 + M_3 \ldots + M_N$$

The total moment of the system divided by the total weight of the system will establish the arm or location of the system's center of gravity:

$$\frac{\text{Total Moment of System, } M_S}{\text{Total Weight of System, } W_S} = \text{System CG}$$

TABLE 4

UH-1C Table of Weights and Moments

			Weight (lbs) (W)	Arm (inches) (A)	Moment/100 (M)/100
Basic Weight UH-1C with Armored Seat			5080.0		7040.0
Ballast			50.0	424.5	212.3
Operating Weight					
Pilot (95th percentile, nude)		203.00			
Copilot (95th percentile, nude)		203.00			
Two each:					
APH-5 Flying Helmet	7.94				
Nomex Flight Clothing (2-piece), Underwear, socks, and belt	6.20				
Combat Boots (13R) Leather Uppers	8.24				
Leather Flying Gloves (Gauntlet Type)	.56				
Revolver with 5 rds. 38 cal. & Shoulder Holster	4.10				
Extra Ammunition, 50 rds. .38 cal.	3.20				
Survival Kit, Individual, Light Weight, Army (Includes Sheath Knife, Flare, Pen)	9.00				
RT10 Survival Radio	4.00				
Thigh Clip Board	1.74				
Aircrew Chest Armor with Carrier (Front Plate Only, Size Long)	29.12				
Fragmentation Protective Vest (Large)	16.00				
Pen Light	.20				
Total Weight of Clothing and Accessories (Pilot Copilot)	90.30 lbs				
Total Weight, Pilot, Copilot, Clothing and Accessories			496.3	46.7	231.6

Data supplied by USAHEL

TABLE 4 continued

		Weight (lbs) (W)	Arm (inches) (A)	Moment/100 (M)/100
2 M-16 Rifles, 6 Magazines		21.0	115.0	24.2
XM-21 System				
External Stores Support				
Cross Beam Assemblies	30.3 lbs			
Fwd Beam Assemblies	13.0			
Aft Beam Assemblies	13.7			
Fwd Sway Brace Assemblies	1.3			
Aft Sway Brace Assemblies	1.5			
Hardware	3.3			
Aft Tube Assemblies	6.8			
Hardware	1.8			
Total		71.7	139.1	99.7
CFE				
Aft Equipment Rack	2.9			
Ammunition Tie Down Rack	12.7			
External Wiring	2.0			
External Hydraulic Installation	3.5			
Hardware	2.9			
Airframe Modifications	.8			
Internal Wiring	11.4			
Hardware	.8			
Sight Support	.1			
Total		37.1	130.4	48.4
GFE				
XM-134 Guns	100.0			
Ammunition Boxes (12)	49.2			
Ammunition Chutes and Loop Clamps	31.0			
Sight Station-Gunner	9.1			
Control Panel	5.6			
Pylon	129.7			
Bomb Rack and Adapters	74.0			
Intervalometer Panel	2.2			
Junction Box	25.0			

TABLE 4 continued

		Weight (lbs) (W)	Arm (inches) (A)	Moment/100 (M)/100
Rocket Pods, LAU-32 B/A	103.0			
Rocket Cables	2.8			
Sight, Pilot-M60C & Bracket	6.9			
Shorting Cables	.8			
Manual Release	3.3			
Total		542.6	133.5	724.4
Engine Oil		28.0	157.0	44.0
Flyaway Kit		10.0	68.0	6.8
Total Operating Weight		6336.7	133.0	8431.4
Takeoff Gross Weight				
Operating Weight Total		6336.7	133.0	8431.4
7.62 Ammo (6000 rds) (XM-21)		390.0	112.0	436.8
7.62 Ammo (120 rds) (M-16)		7.0	115.0	8.1
2.75 Rockets (14)		302.3	132.9	401.8
Smoke Grenades (12)		19.5	115.0	22.4
Fuel -- 242 Gallons (Full Capacity)		1573.0	136.7	2150.3
Total Takeoff Gross Weight		8628.5	132.7	11450.8
Total Takeoff Gross Weight Less Fuel Weight		7055.5	131.8	9300.5

With the aircraft's takeoff gross weight and CG values tabulated, these numbers can then be compared against the aircraft's CG limits graph and the takeoff gross weight limitations graph presented in the aircraft operator's manual.

The CG limits graph (Fig. 5) is used to define the forward and aft shift limits that the CG may undergo and still render the aircraft operable.

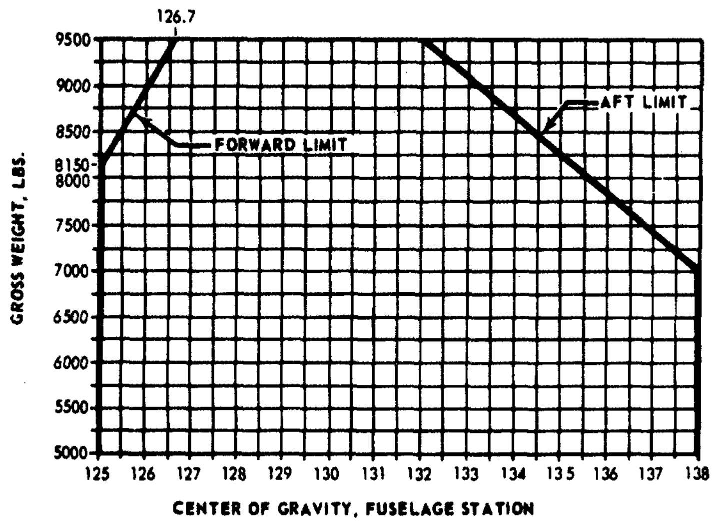


Fig. 5. UH-1C/CG LIMITS GRAPH*

The takeoff gross weight limitations graph (Fig. 6) is used to project a maximum takeoff gross weight as limited by the aircraft's vertical-climb performance. Maximum takeoff gross weights are given as a function of pressure altitude, outside air temperature, and the desired vertical rate of climb.

* Department of the Army, 1968c.

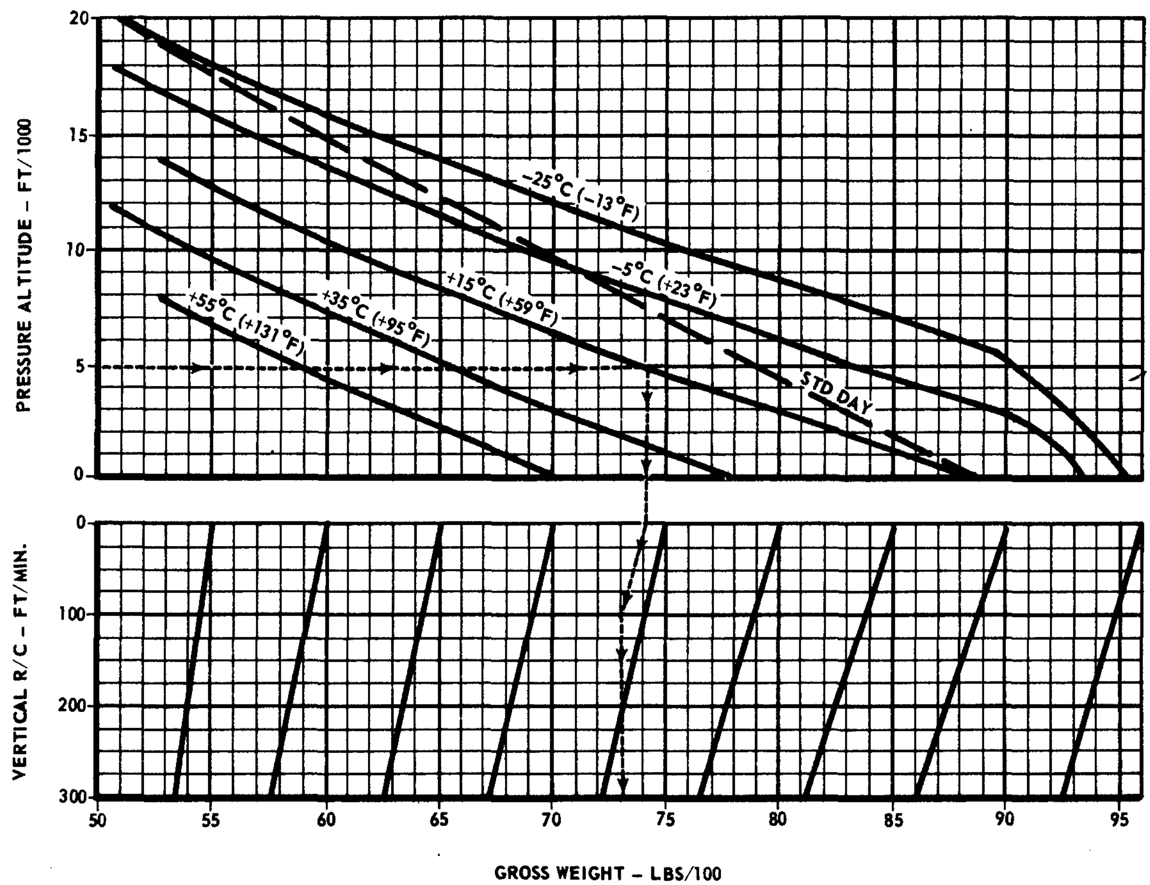
TAKE-OFF GROSS WEIGHT LIMITATIONS

C

CLEAN CONFIGURATION
MAXIMUM GROSS WEIGHT FOR HOVERING
OUT OF GROUND EFFECT WITH TAKE-OFF POWER
6600 RPM 2°C INLET TEMP. RISE

MODEL: UH-1C
DATA AS OF: February, 1964
DATA BASIS: Military Potential Test of the "Door Hinge" Rotor System

ENGINE: Lycoming T53-L-11
FUEL GRADE: JP-4
FUEL DENSITY: 6.5 LBS/GAL



REMARKS: (1) The graph normally used for Specific Humidity Correction has been intentionally omitted as the free shaft turbine is not materially affected by humidity changes.

(2) Gross weight corrections for vertical rate of climb calculated at +35°C and are slightly conservative when used at lower temperatures.

Fig. 6. SAMPLE OF UH-1C TAKE-OFF GROSS WEIGHT LIMITATIONS*

* Department of the Army, 1968c.

Applying the desired performance requirements (pressure altitude, operating temperature and vertical rate of climb) from the mission profile to the gross weight limitations graph yields the maximum gross-weight lifting ability of the aircraft for the given conditions. The takeoff gross weight from the weight and moments table (Table 4) must be equal to or less than this limit (i.e., TOGW $\lesseqgtr$ TOGWL). If the result of these comparisons is negative, indicating that the aircraft is overweight or outside the CG limits, then the system must be reconfigured and the weight and balance values recalculated.

If the result of the comparisons is positive, then the feasibility of adding armor weight to the system must now be determined by computing a performance matrix.

Computational Methods

Subtracting the aircraft's takeoff gross weight from the takeoff gross-weight limit indicates the amount of armor that may be added to the system:

$$\text{The expression reads -- } W_A = \text{TOGWL} - \text{TOGW} \qquad (1)$$

If the resulting value is insufficient to provide the crew with added protection, additional allocations may be obtained by reducing the aircraft's gross weight or by trading off the aircraft payload (fuel and ammunition) for armor. To establish the relationship between the allowable armor weight and payload weight within the takeoff gross-weight limit, the takeoff gross weight, as used above, is broken down as follows:

Takeoff gross weight = operating weight + fuel weight + munitions weight (see Weights and Moments table, Table 4).

The equation may then be expressed as:

$$W_A = \text{TOGWL} - (W_O + W_F + W_M) \qquad (2)$$

To establish the total amount of payload weight that may be used for tradeoff, the equation becomes:

$$\text{TOGWL} - W_O = W_F + W_M + W_A \qquad (3)$$

The known factors in the equation are:

Takeoff gross-weight limit	TOGWL

Aircraft operating weight	W_O*
Maximum fuel weight	W_F*
Maximum munitions weight	W_M*

The unknown to be found is armor weight W_A.

Varying the payload weight, fuel weight (W_F), and/or munition weight (W_M), in Equation (3) will result in a set of values for armor weight (W_A). Each payload weight for armor weight tradeoff will occasion a shift in the system's total moment (center of gravity). These CG shifts are caused by the new forces acting on the aircraft from various locations within the system; i.e., payload weight reduction/armor addition.

Since the aircraft has definite CG limits, the impact of these new forces on the system's CG must be established. As cited above, the total moment of system divided by the total weight of system indicates the location of the aircraft system's center of gravity; i.e., $\frac{M_S}{W_S} = CG$.

The new moments to be studied will be those due to changes in payload weight and armor additions. An expression combining these factors to compute the system's new total moment is:

$$M_S = M_O + M_F + M_M + M_A, \text{ where:} \tag{4}$$

M_S = Moment of System

M_O = Moment of Craft at Operating Weight

M_F = Moment of Fuel

M_M = Moment of Munitions

M_A = Moment of Armor.

* See Weights and Moments table (Table 4).

By definition, $M = WA$ where W = weight and A = arm or distance of weight from datum.

$M_S = W_S A_S$, $M_O = W_O A_O$, $M_F = W_F A_F$, $M_M = W_M A_M$, and

$M_A = W_A A_A$, where:

W_S = Weight of System (Aircraft at Takeoff Gross Weight)

W_O = Aircraft at Operating Weight

W_F = Fuel Weight

W_M = Munitions Weight

W_A = Armor Weight

A_S = Arm of System (Distance of Takeoff Gross Weight from Datum)

A_O = Arm of Operating Weight

A_F = Arm of Fuel Weight

A_M = Arm of Munitions Weight

A_A = Arm of Armor Weight

By substitution, equation (4) becomes:

$$W_S A_S = W_O A_O + W_F A_F + W_M A_M + W_A A_A \tag{5}$$

Also,

$$W_S = W_O + W_F + W_M + W_A \tag{5a}$$

Substituting (5) into (4), (4) becomes:

$$(W_O + W_F + W_M + W_A) A_S + W_O A_O + W_F A_F + W_M A_M + W_O A_O \tag{6}$$

Dividing:

$$A_S = \frac{W_O A_O + W_F A_F + W_M A_M + W_A A_A}{W_O + W_F + W_M + W_A} \tag{6a}$$

$$A_S = \frac{M_O + M_F + M_M + M_A}{W_O + W_F + W_M + W_A}$$

Equation (6b) is an expression for the location of the system's center of gravity (A_S); i.e., A_S (CG) = $\frac{\text{Total Moments}}{\text{Total Weight}}$.

Before Equation (6b) can be used, the following data are required:

Location of Reference Datum.

The Operating Weight (W_O) of the aircraft.

Distance (Arm) from Datum of:

Arm of Operating Weight	A_O
Arm of Fuel Weight	A_F
Arm of Munitions Weight	A_M
Arm of Armor Weight	A_A

The arm or distances (A_O, A_F, A_M) can be found in the aircraft operator's manual or can be plotted on the aircraft's inboard profile drawings. The center of mass for the added armor weight at this stage must be assumed to establish a constant value for the armor. Therefore, A_A will be constant.

Note: Since the moment of the armor system is assumed at this stage, chances are the center of mass for the actual armor system, when developed, will not be located at this assumed point. Therefore, after the armor system has been developed, the true center of mass for the actual armor system can be computed and applied back into the equations to establish the specific system changes.

Example:

For the UH-1C study aircraft, the center of mass for the armor was assumed to be located at the pilot's seat reference point (58.6).

From the CG limits graph (Fig. 5) establish the forward or aft CG limit for use in Equation (6b). This limit is used as the system's desired center of gravity (A_S) at takeoff gross weight in the computations, since exceeding this limit would make flight impossible.

Example:

Using the forward CG limit from the UH-1C/CG Limits Graph as the desired CG for the system (A_S) in the final tradeoff computations, the weight and location of the fuel results in a tail-heavy aircraft (Fig. 7). A certain amount of armor forward of the desired CG together with the ammunition weight would off-set a given fuel weight and allow the system to balance. The aircraft must maintain this balance throughout the mission on takeoff, in the air and on the ground. This consideration dictates the requirement to compute what amount of a given payload (fuel and ammunition) must be reserved as ballast for a given amount of armor addition/ payload (fuel and ammunition) expenditure.

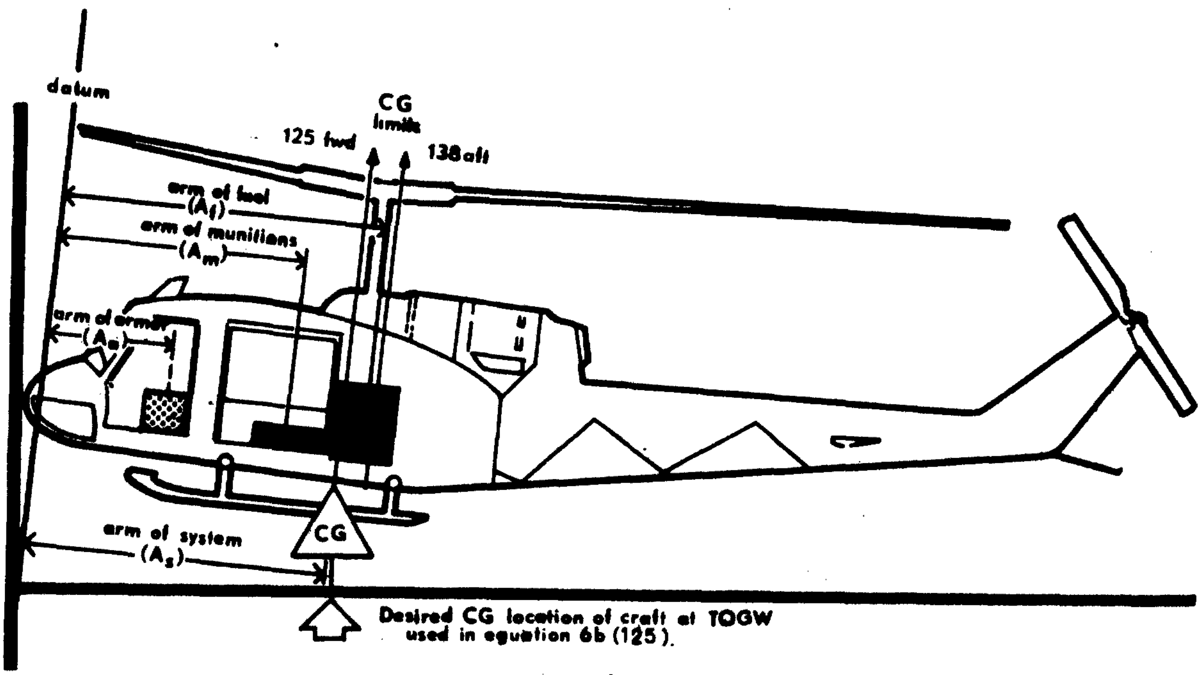


Fig. 7. UH-1C STUDY AIRCRAFT WEIGHT AND BALANCE

The results of these computations yield the aircraft's performance matrix, which for a given amount/location of armor indicates the total payload weight allowable and the mission endurance inherent in this payload weight; i.e.,

Flight Endurance: Fuel Weight = Fuel Weight Usable
+ Fuel Weight Ballast ($W_F = W_{F_U} + W_{F_B}$)

Munitions Endurance: Munitions Weight = Munitions Weight Usable + Munitions Weight Ballast ($W_M = W_{M_U} + W_{M_B}$)

Note: Since Figure 7 indicates that the tradeoff in the UH-1C example would be between fuel weight for armor weight only, Equation (3) would be revised to indicate the total amount of weight available for a tradeoff between these two factors. Equation (3) revised for UH-1C example becomes:

$$TOGWL - W_O + W_M = (W_F + W_A) \tag{3a}$$

Equation (6b) would then be used to compute the changes in the system due to various fuel weight for armor weight tradeoffs by holding all values constant except fuel weight (W_F) and armor weight (W_A).

Solving Equation (6) for fuel weight (W_F), the equation becomes (removing brackets):

$$W_A A_S + W_F A_S + W_M A_S + W_O A_S = W_A A_A + W_F A_F + W_M A_M + W_O A_O \tag{7}$$

Transferring term involving W_F to left:

$$W_F A_S = W_F A_F = W_A A_A + W_M A_M + W_O A_O - W_A A_S + W_M A_S + W_O A_S \tag{8}$$

Collecting like terms:

$$W_F (A_S - A_F) = W_A (A_A - A_S + W_A (A_M - A_S) + W_O (A_O - A_S) \tag{9}$$

Solving for (W_F):

$$W_F = W_A \left(\frac{A_A - A_S}{A_S - A_F}\right) + W_M \left(\frac{A_M - A_S}{A_S - A_F}\right) + W_O \left(\frac{A_O - A_S}{A_S - A_F}\right) \tag{10}$$

Armor weights (W_A) are substituted into Equation (10) and the resulting fuel weights (W_F) establish the aircraft's performance matrix.

Example:

Using the UH-1C data from the Weights and Moments table (Table 4), Equation (10) is used to establish the UH-1C performance matrix as follows:

Weights and Moments Data (UH-1C)

		Weight		Arm
Operating Weight	(W_O)	6336.7	(A_O)	133.0
Munitions Weight	(W_M)	719.0	(A_M)	120.4
Fuel Weight	(W_F)	1573.0	(A_F)	136.7
Armor Weight	(W_A)		(A_A)	58.5
Arm of System (Desired CG of aircraft at takeoff gross weight from CG limits graph)			(A_S)	125.0

Solving Equation (10) for fuel weight (W_F), the equation becomes:

$$W_F = W_A \frac{(58.5 - 125)}{125 - 136.7} + 719.0 \frac{(120.4 - 125)}{125 - 136.7}$$

$$+ 6336.7 \frac{(133.0 - 125)}{125 - 136.7}$$

$$W_F = W_A (5.6837) + 719.0 (.393) + 6336.7 (.6837)$$

$$W_F = W_A (5.6837) + 282.68 - 4332.4$$

$$W_F = W_A (5.6837) - 4049.7217$$

Since $W_F = W_{F_U} + W_{F_B}$, it is logical to establish the point at which fuel ballast is required to offset armor weight.

Solving for W_A, when $W_{F_B} = 0$:

$$W_A (5.6837) - 4049.7217 = 0 \; W_{F_B}$$

$$W_{F_B} = 712.5150 (5.6837) - 4049.7217$$

$$W_{F_B} = 4049.7215 - 4049.7217$$

$$W_{F_B} = -0.0002$$

These computations indicate that any armor weight (W_A) at station 58.5, under 712.5 lbs. would not require fuel ballast to balance the system.

Referring back to Equation (3a) page 29:

$$TOGWL - W_O + W_M = (W_F + W_A)$$

$$8780 - 6336.7 + 719 = 1724.3$$

The amount of fuel weight available when 712.5 lbs. of armor is applied is established by:

$$(W_F + W_A) - W_A = W_F \tag{11}$$

$$1724.3 - 712.5 = 10118 \text{ lbs fuel weight}$$

Hours flight endurance is found as follows:

$$W_F - W_{F_B} = W_{F_U} \tag{12}$$

$$10118 - 0 = 10118 \text{ fuel usable}$$

Dividing the usable fuel weight by the aircraft's consumption rate (operator's manual) indicates the aircraft's flight endurance:

$$\frac{10118 \text{ lbs. usable fuel}}{450 \text{ lbs. per hr.}} = 2.2484 \text{ hrs. endurance}$$

Substituting various armor weights (W_A) into Equation (10) establishes various fuel weights; i.e., ($W_{F_U} + W_{F_B}$). These corresponding values are then tabulated in a performance matrix similar to the UH-1C example (Table 5).

TABLE 5

UH-1C Performance Matrix Example

A_A	W_A (lbs)	Fuel Payload (lbs) W_F	W_{F_B}	W_{F_U}	Flight Endurance (hrs)
58.5	100	1,624.3	0	1,624.3	3.6
	200	1,524.3	0	1,524.3	3.4
	300	1,424.3	0	1,424.3	3.2
	400	1,324.3	0	1,324.3	2.9
	500	1,224.3	0	1,224.3	2.7
	600	1,124.3	0	1,124.3	2.5
	700	1,024.3	0	1,024.3	2.3
	713	1,011.3	2.75	1,008.5	2.2
	720	1,004.3	42.5	961.8	2.1
	730	994.3	99.3	894.9	1.9
	740	984.3	156.2	828.1	1.8

Total tradeoff weight; i.e., $(W_F + W_A)$ = 1,724.3 lbs.
Consumption rate - 450 lbs/hr

SUMMARY

After the performance matrix has been constructed for the existing aircraft, the required mission endurance taken from the mission profile will determine the amount of armor that can be selected. That armor weight which yields the endurance time nearest this mission time will be the most acceptable under said conditions. If, at this point, sufficient weight for armor addition is not available, a decision must be reached before continuing the study. When no configuration or mission requirement changes can be made in the system to allow for additional weight allocations, the continuation of the study is not worthwhile. Where modifications can be made in the system or mission, the resulting new weight and balance constraints must be tabulated. If sufficient weight is available, then the aircrew's "protection need" can be assessed in Phase II.

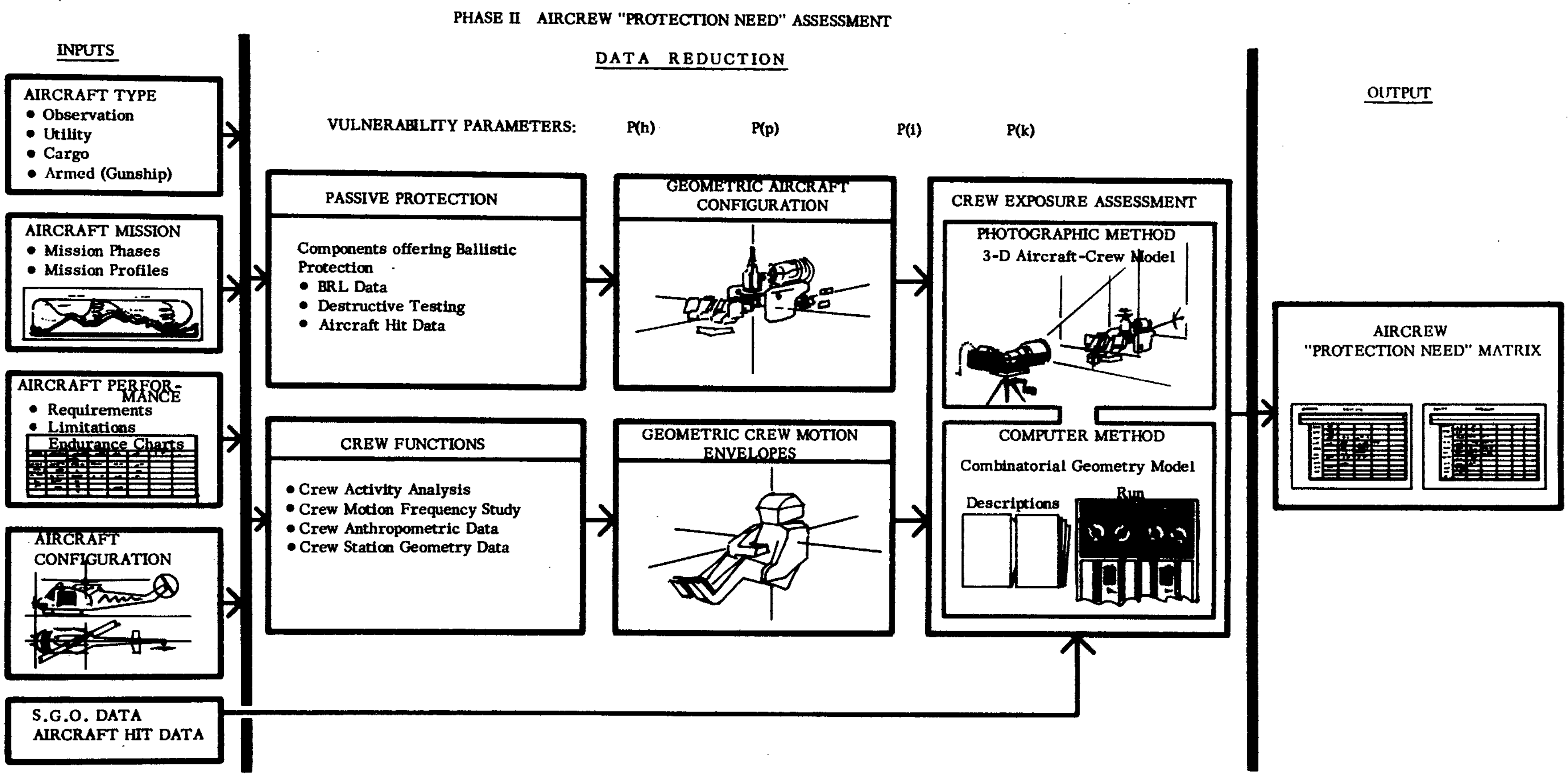


Fig. 8. PHASE II FLOW CHART

PHASE II - AIRCREW "PROTECTION NEED" ASSESSMENT

PURPOSE

This phase of the guideline is used to quantitatively assess the crew's "protection need" within the total system.

INPUT DATA

The crew's "protection need" assessment is based primarily on the type of enemy weapons encountered, the aircraft components offering passive protection, and the location of the crew in relation to these components. The latter two considerations dictate the requirement to have the aircraft components and crew location solidified before Phase II can be initiated. Following design conceptualization, the aircraft's type, mission, configuration and performance data will become specific inputs for various facets of Phase II as shown in the flow diagram (Fig. 8). Given this data, the crew's "protection need" assessment can be accomplished using the following study methodology.

"PROTECTION NEED" ASSESSMENT METHODOLOGY

To achieve a fair degree of accuracy in this assessment, each crewman's body is divided into seven body parts (Fig. 9). Each body part is analytically assigned a number "n," where "n" defines its "protection need" while it is properly positioned in the crew station. Computations of any given "n" are based on the obtained probability values of four parameters:

P(h) - The probability distribution of projectile hits from ground fire about the aircraft by direction.

P(p) - The probability of a projectile from a particular direction penetrating a particular section of the crew motion envelope.

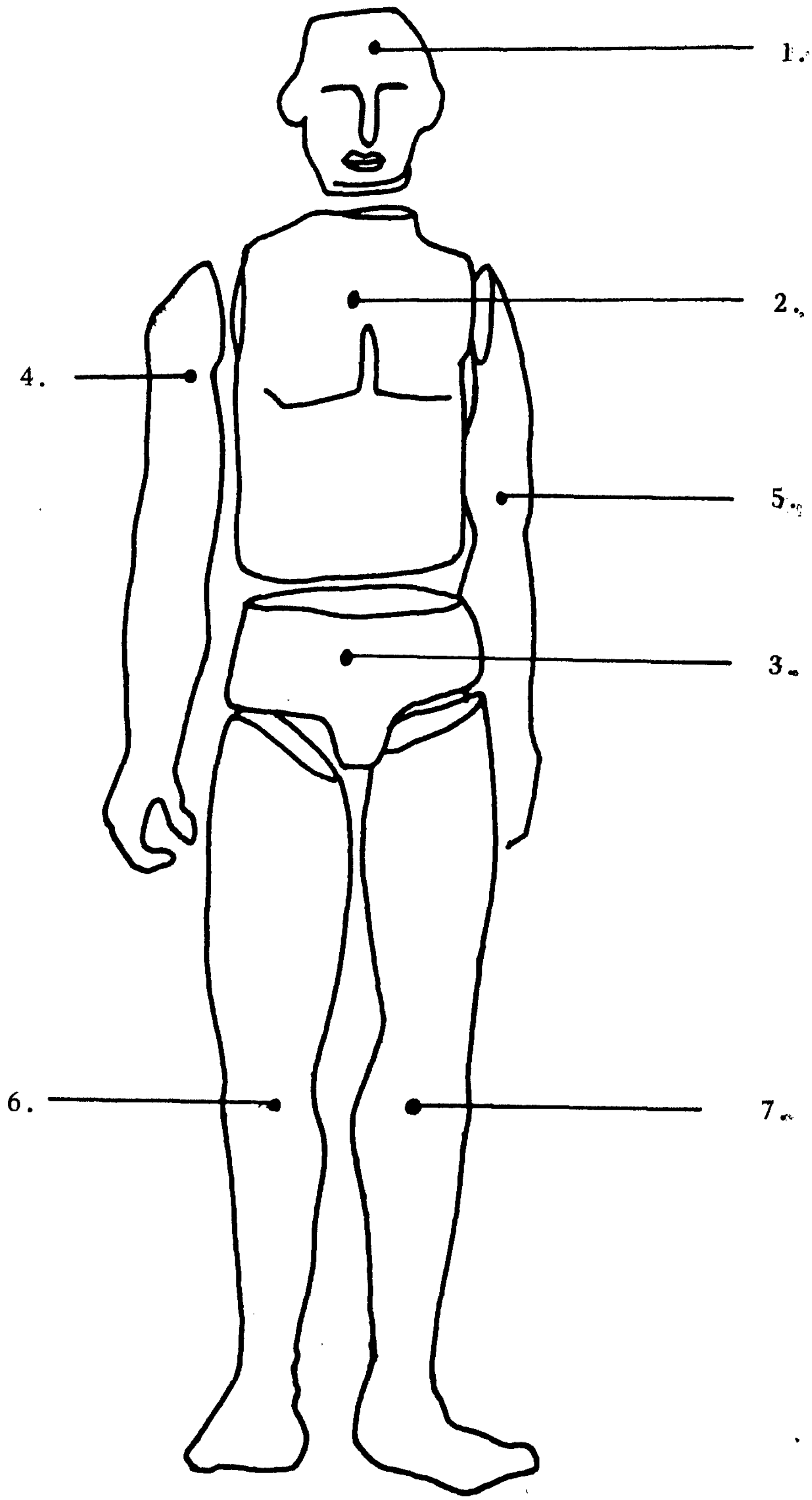


Fig. 9. BODY DIVISION FOR AIRCREW "PROTECTIVE NEED" ASSESSMENT DEVELOPED FROM SURGEON GENERAL'S WOUND BALLISTICS REPORTS

P(i) - The probability of hitting a particular body part, i, in a particular section of the crew motion envelope.

P(k) - The probability of kill of a man by body part.

Following is a detailed discussion of the pertinent data and analysis techniques employed to obtain the probability values for each vulnerability parameter. Examples of each analysis technique are presented when appropriate.

Vulnerability Parameters

P(h) - The probability distribution of projectile hit from ground fire about the aircraft by direction. This probability is a function of the maneuvers and tactics executed and the enemy's pattern of fire. To incorporate this information as input data, an analysis is made of the aircraft's projected mission and operating environment. This information would use current BRL hit-distribution data indicating the priority of fire zones (azimuth angles) around the aircraft. The mathematical expression P(h) represents a value between 0 and 1 which indicates the probability of hit assigned to a particular direction. Because of the lack of accurate data on hit distributions, the following assumption is made: Hits on the aircraft are equally probable from all directions. Hence, P(h) = 1. As additional information becomes available, it is expected that other values of P(h) will be established for particular directions of fire.

P(p) - The probability of a projectile from a particular direction penetrating a particular section of the crew motion envelope. This vulnerability parameter is a function of the following inputs:

a. Location of components offering ballistic protection. As expanded in Phase I of the guideline, the aircraft's projected mission, performance and operating environment are studied to determine the aircraft's basic component configuration. From this basic configuration the components offering ballistic protection to the crew are selected according to the characteristics of the projectile providing the threat and the components providing protection. The amount of component protection can be based either on the opinions of experienced ballistics personnel, or, if available, data collected from destructive testing.

b. The location of the crewman in relation to the components offering ballistic protection. To establish the location of the crewmen during the aircraft mission and to integrate this data within the guideline methodology, the following study techniques were devised:

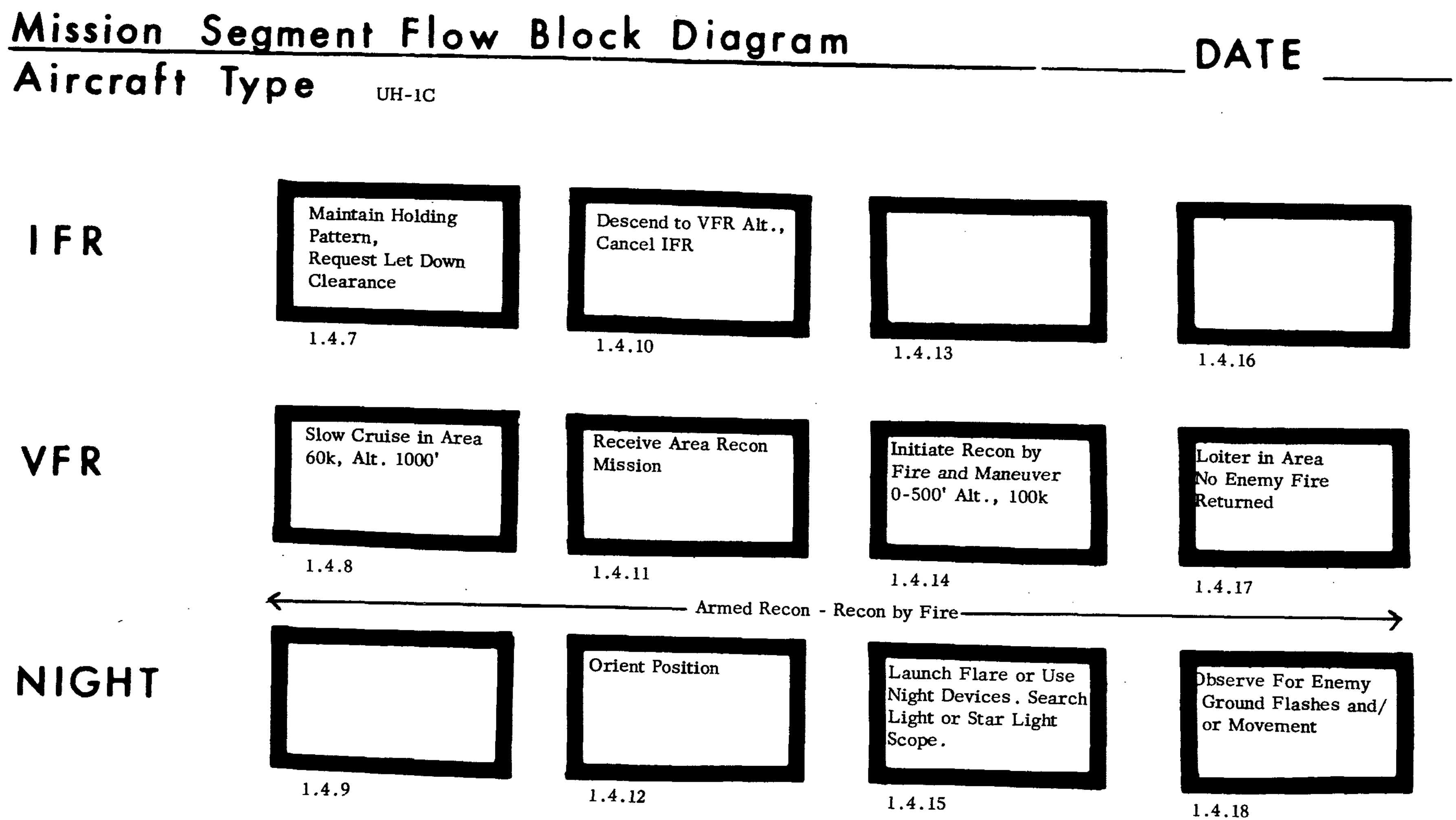


Fig. 10. ACTIVITY ANALYSIS INDEX

(1) Mission-oriented crew activity analysis: Determining the crew body positions during mission time begins with a mission-oriented crew activity analysis where the various phases embodied in the aircraft mission profiles are analyzed to project the required crew tasks and their sequence. For study purposes, a block-flow analysis technique was utilized to subdivide the mission phases into workable modules with the crew's activities sequentially indexed and coded for easy reference. Figure 10 illustrates this technique. (See Appendix A for the complete Activity Analysis.)

(2) Crew motion-frequency study: Subsequent to the crew-activity analysis, the basic functions critical to the aircraft mission are selected from the Activity Index and applied as inputs to a crew motion-frequency study. Data collected pertains to the frequency with which the crew performs tasks related to aircraft control, navigation, communication, ordnance delivery, etc., and would indicate those crew body positions most frequently taken during the critical mission time. Photographs of these selective body positions are then utilized to generate the appropriate aircrew motion envelopes.

Example: UH-1C Crew Motion-Frequency Study

A frequency-of-events study was conducted at Ft. Rucker, Ala., during Warrant Officer Candidates field training exercises. The observer flew in various UH-1 aircraft to obtain the needed data. A sample size of 15 missions was established. The observations were divided into eight "gun" ship and seven "slick" ship missions and performed under both day and night conditions. Readings were taken at five-minute intervals with randomized starting times.

Eleven basic functions covering the spectrum of crew activities were selected for study:

Preflight check.
Engine start procedure.
Engine run-up test.
Frequency changes and establishing communications.
Hovering turns.
Climbing, descending and banking turns.
Navigation sequence.
Sighting and firing weapons.
External load hook-up and release.
Radiological survey.
Landing aircraft and shutdown procedures.

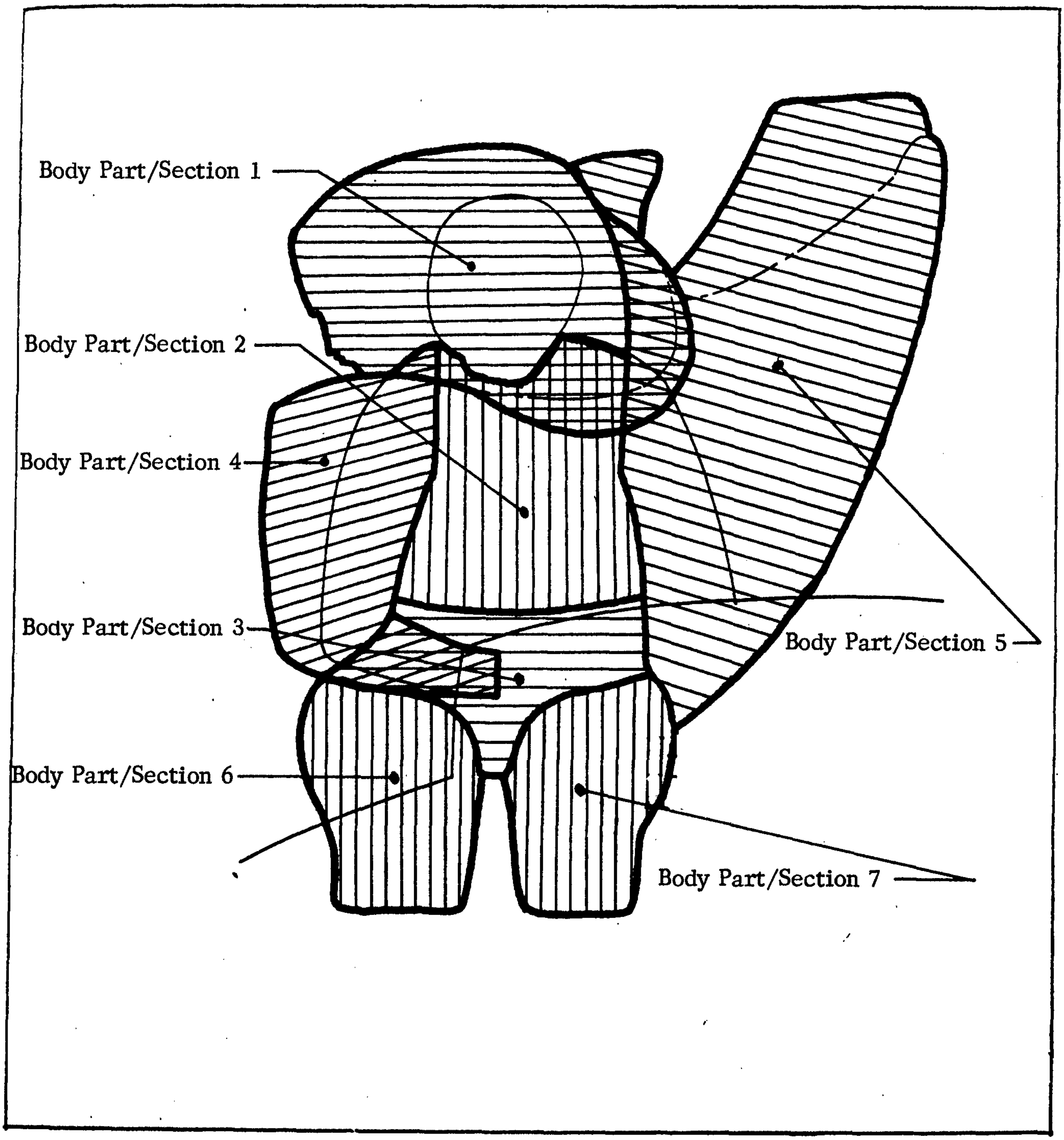


Fig. 11. EXAMPLE OF MAXIMUM MOTION ENVELOPE WITH BODY PARTS/SECTIONS INDICATED

Data collected pertained to the frequency with which the pilot and copilot were performing tasks with relation to the following aircraft components: center console, overhead console, cyclic and collective. Readings were also taken pertaining to radio usage, i.e., intercom, UHF and FM (see Appendix B for the complete motion study).

The study provided the following data:

Pilot: Position of pilot's hands and arms (percent of total time)

Collective (left hand)	92%
Cyclic (right hand)	92
Overhead console	3
Center console	5

Copilot:

Mission functions:

Navigation	45%
Observation/target detection	35
Weapon systems	20

Radio usage (percent of total navigation time)

UHF	30%
FM	10
Inter-communication	33
No communication	27

(3) Crew motion envelopes: Photographs of the significant crew tasks indicated by the motion-frequency study are used in conjunction with detailed anthropometric and crew-station measurements (Department of Defense, 1956) to generate the aircrew motion envelopes. The motion envelope is a graphic method of accurately describing the complete range of motion traced by each body part as a crewman performs his assigned tasks. The range of motion for each body part in turn contributes one section to the total motion envelope as seen in Figure 11. A description of the motion-envelope development sequence is as follows:

Example:

Front and side-view photographs are taken simultaneously of both 5th and 95th percentile crewmen, seated in the aircraft, performing the significant functions and tasks required in that crew station (Figs. 12 and 13). The number of photographs taken at each station depends upon the number of significant tasks and the complexity of motion involved in performing these tasks as indicated by the mission-oriented functional analysis (Appendix A).

Photographs are scaled and arranged in a series (5th percentile pilot front views, 95th percentile pilot side views, etc.).

Tracings are made of each photograph in a particular series noting the seat reference point and the contour or envelope lines of the crewman's body parts; i.e., head, torso, etc.

All tracings of a particular series (95th percentile pilot side views) are stacked and an initial composite outline tracing is made incorporating the body parts of the crewman relative to the eye point, seat reference point, rudder pedals, cyclic limits, collective limits, etc. This is done for each series of photographs (Fig. 14).

The corresponding outline composites are matched (5th percentile pilot front view matched with 5th percentile pilot side view) and are used to develop a third view (5th percentile pilot top view) using drafting board techniques. Both 5th and 95th percentile crewmen, of a particular station, now have a three-view drawing (Figs. 15 and 16).

These three-view drawings are now used to develop the final three-view composite motion envelope. As an example: the 5th percentile pilot/three-view drawing is overlaid with the 95th percentile pilot/three-view drawing. The resulting composite tracing is the final pilot motion envelope -- a front, side and top view figure which represents both 5th and 95th percentile crewmen (Fig. 17).

Fig. 12. OVERALL VIEW OF CREW MOTION STUDY ACTIVITIES
(UH-1B, crew station modified to a UH-1C; placement of cameras, timers and personnel)

Fig. 13. CLOSEUP VIEW OF CREW MOTION STUDY ACTIVITIES SHOWING 95TH PERCENTILE ARMY AVIATOR PERFORMING CREW FUNCTIONS (Windshield and doors have been removed to reduce light reflections and visual masking of crew.)

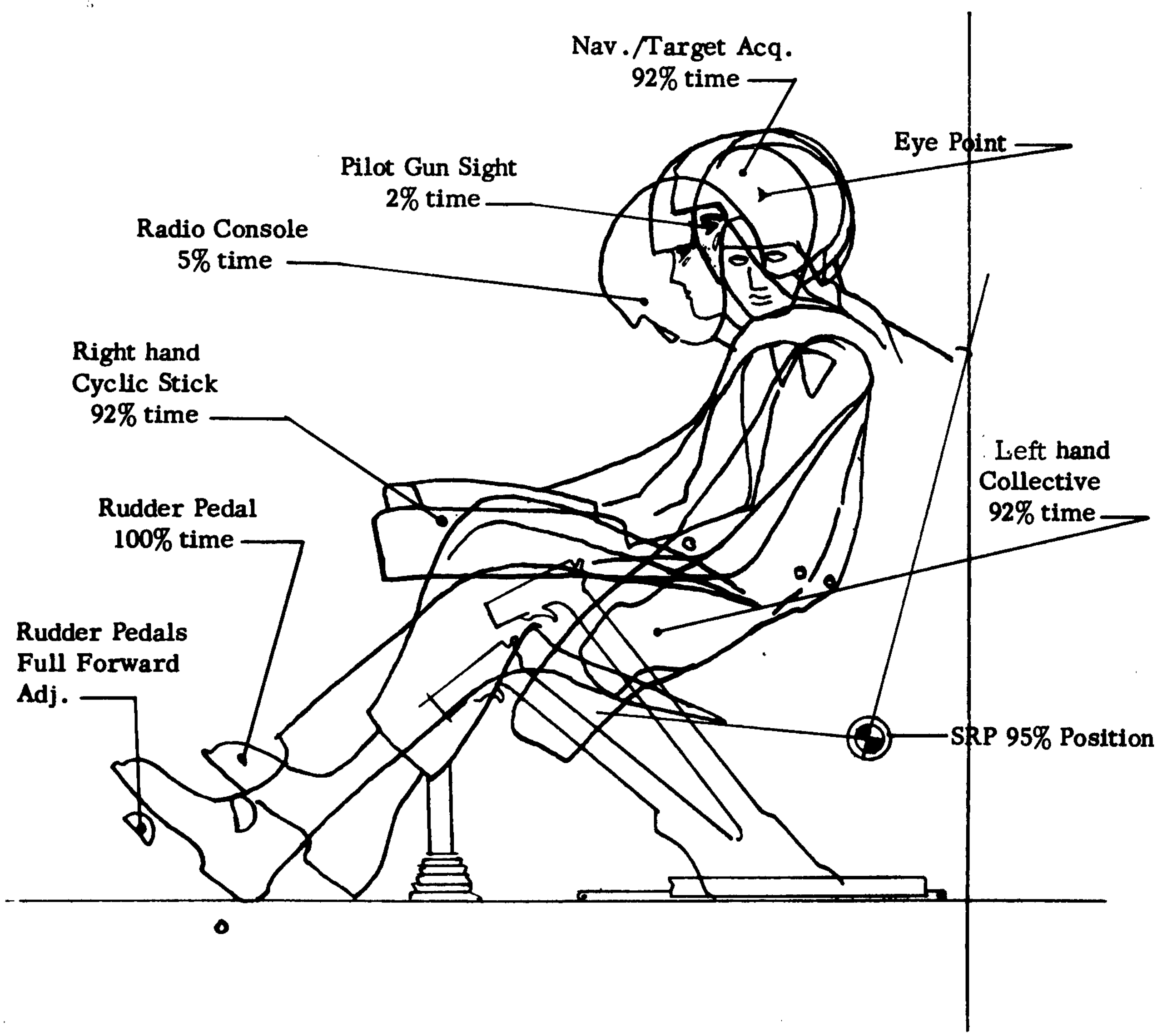


Fig. 14. INITIAL 95TH PERCENTILE PILOT/UH-1C SIDE VIEW COMPOSITE ENVELOPE

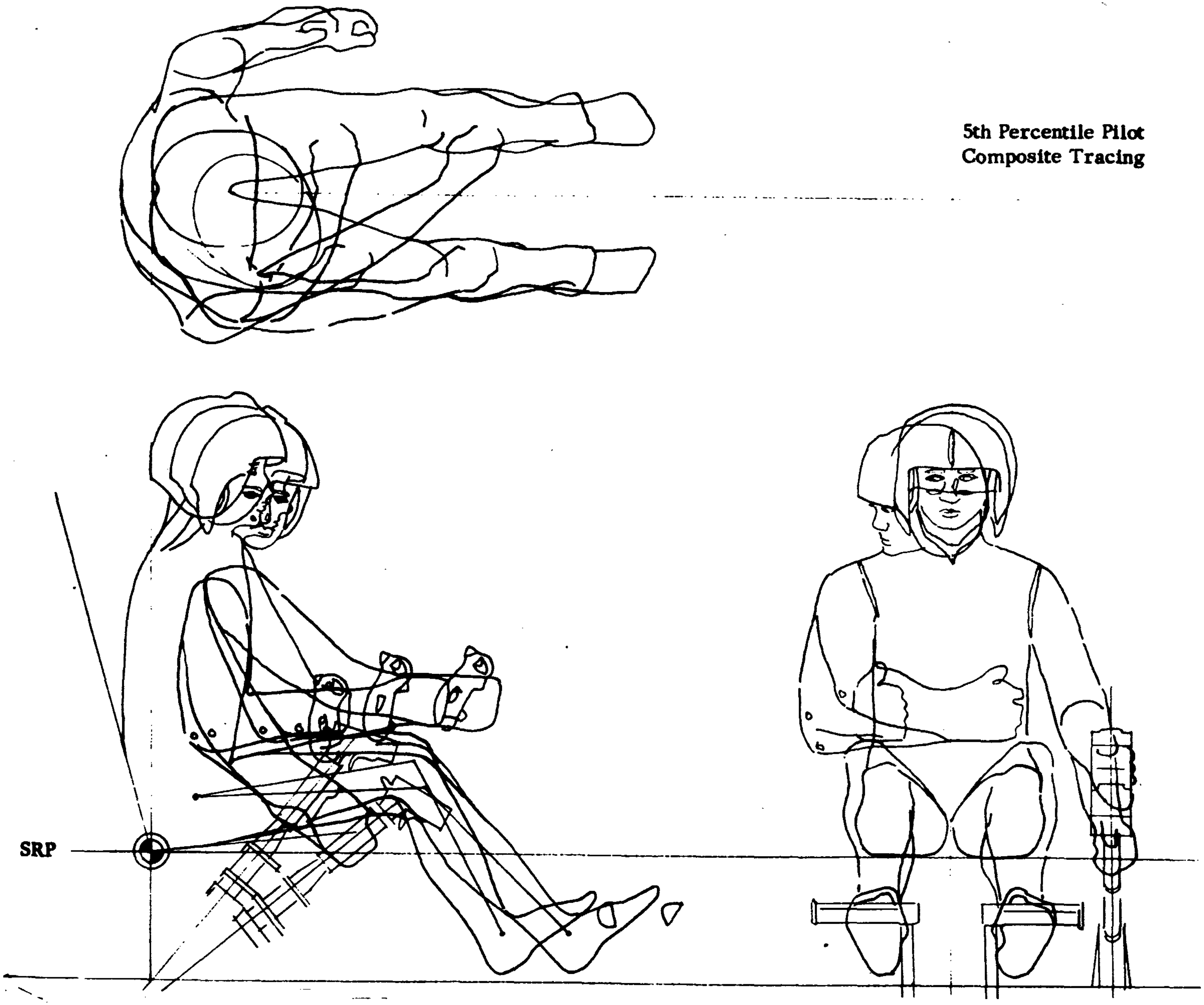


Fig. 15. 5TH PERCENTILE CREWMAN

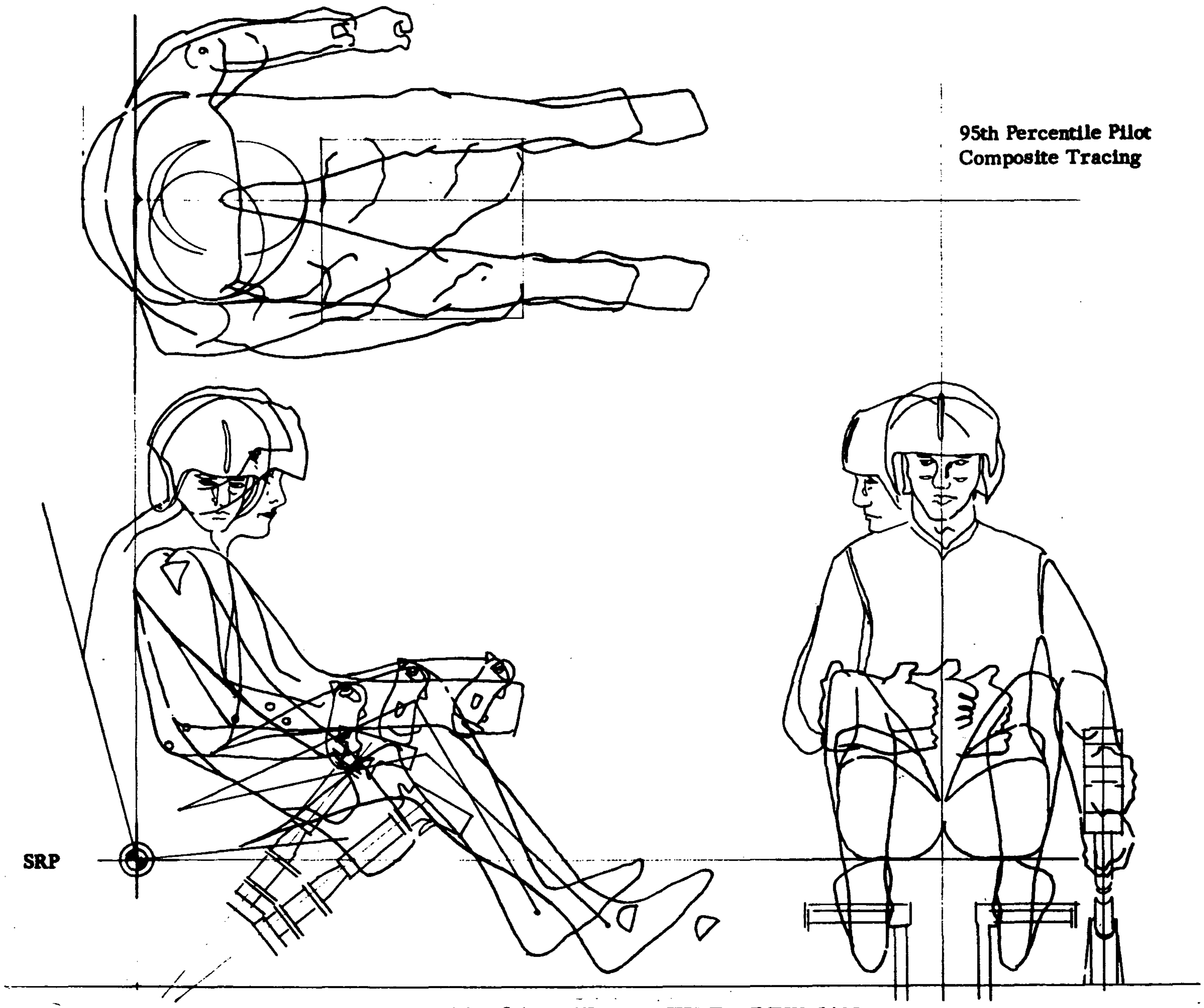


Fig. 16. 95TH PERCENTILE CREWMAN

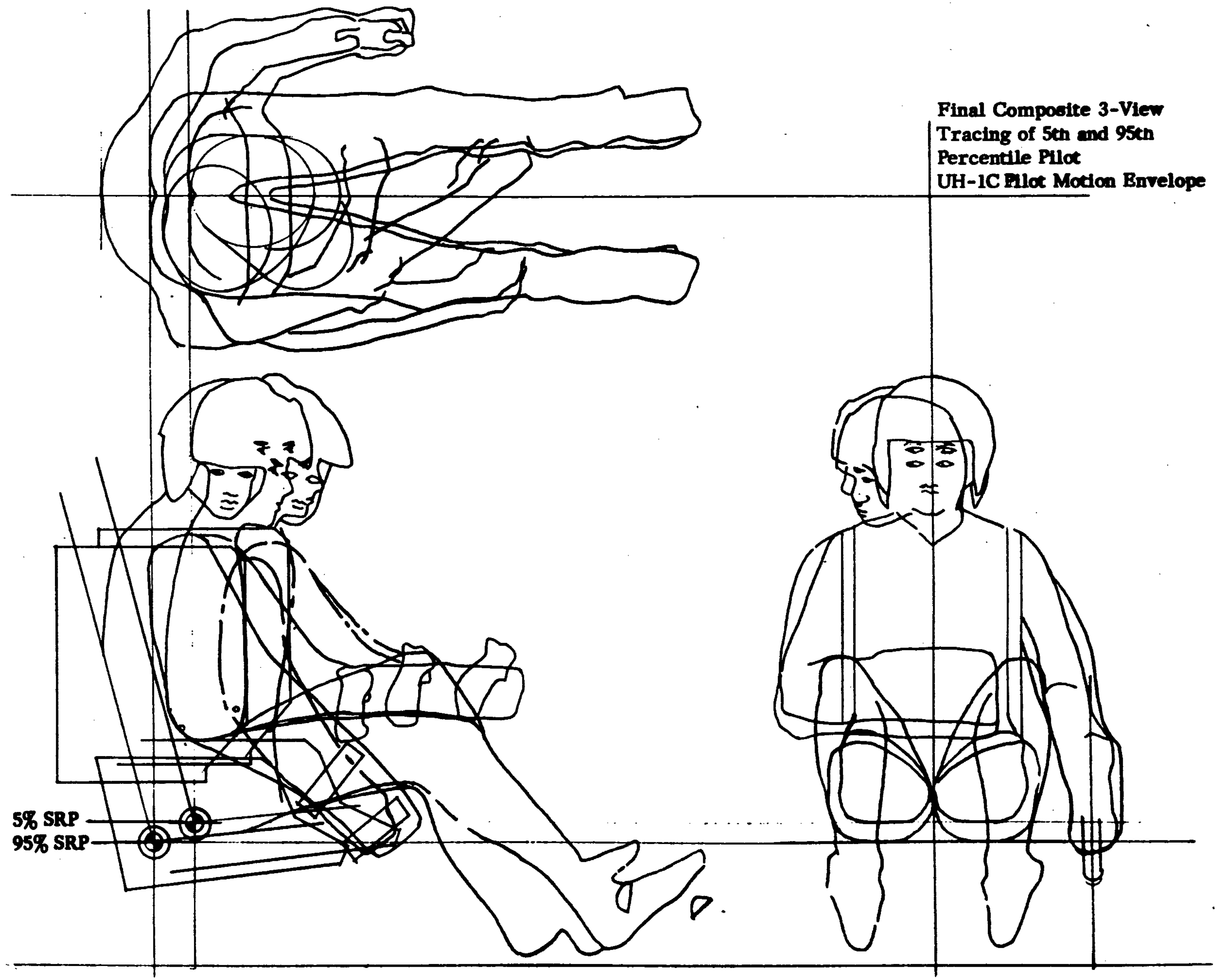
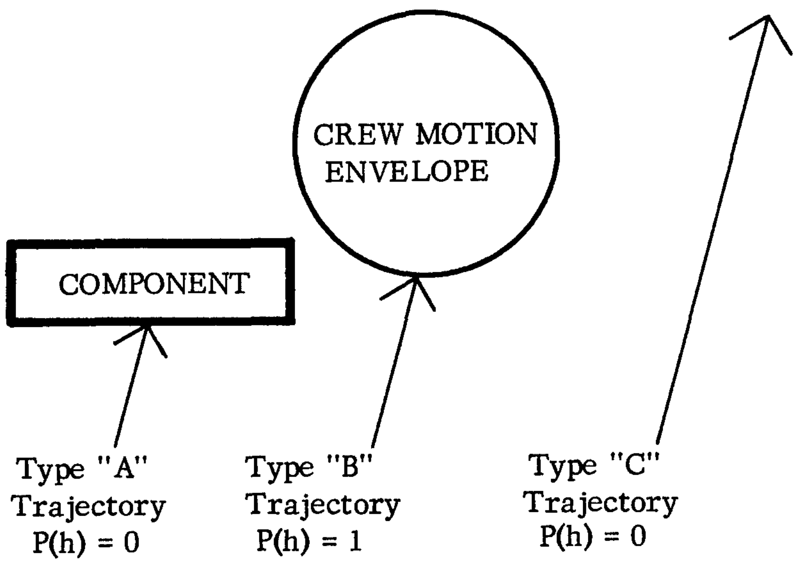


Fig. 17. FINAL COMPOSITE TRACING

c. Crew-exposure assessment. With the projected aircraft system's significant components selected, and the crew motion envelopes developed, the probability of penetrating the motion envelope P(p) values can be determined using the basic principles illustrated in Figure 18.



NOTE: All projectiles are assumed to arrive parallel to the direction of fire.

Fig. 18. BASIC TRAJECTORIES FOR PENETRATION PROBABILITIES

Of the three types of trajectories illustrated, only type "A" and type "B" are considered in this study. Type "A" represents projectiles which hit a component offering the crewmen ballistic protection and do not penetrate the crewman's motion envelope. Type "B" indicates projectiles which are not stopped by a component and do penetrate to the crewman's motion envelope.

The probability of a projectile from a particular direction penetrating the crew motion envelope P(p) is determined by locating each section of the crew motion envelope and noting what components lie between the observer and that section. Since projectiles were assumed to arrive parallel to the line of observation, it is assumed that those sections only partially covered by a component are considered penetrated. The P(p) values for these sections would be one, indicating penetration. The sections of the crew motion envelope that are completely covered by a component(s) are given P(p) values of zero, indicating no penetration. Thus, with this assumption, the expression P(p) will always have a value of either one or zero.

Using these basic principles as a guide, two graphic methods were developed to determine the P(p) values for this second parameter.

(1) Three-dimensional (3-D) photographic model technique.

In the 3-D method, a scale model containing only significant aircraft components and scale manikins representative of the crew motion envelope is fabricated and photographed from various angles.

Example:

A UH-1C 1/10 scale model consisting of components and manikins was fabricated and photographed utilizing a model stand which allowed adjustment of the model in both elevation and azimuth (Figs. 19, 20, and 21). The camera, a 35 mm/SLR with a 600 mm telephoto lens, was fixed 50 feet from the stand, and aimed at the CG of the model. The 600 mm lens was used to achieve a minimum of distortion in the photographs. With this setup, the model was conceptualized as the center of an imaginary sphere which was circumscribed by 22 1/2-degree azimuth and elevation lines. Photographs were taken at every intersection of these lines and visually examined to determine the probability of a projectile penetrating the crew motion envelope(s) from the direction of fire represented by the photo. This determination was made by locating each section of the motion envelope and noting what component(s) lies between the observer and that section.

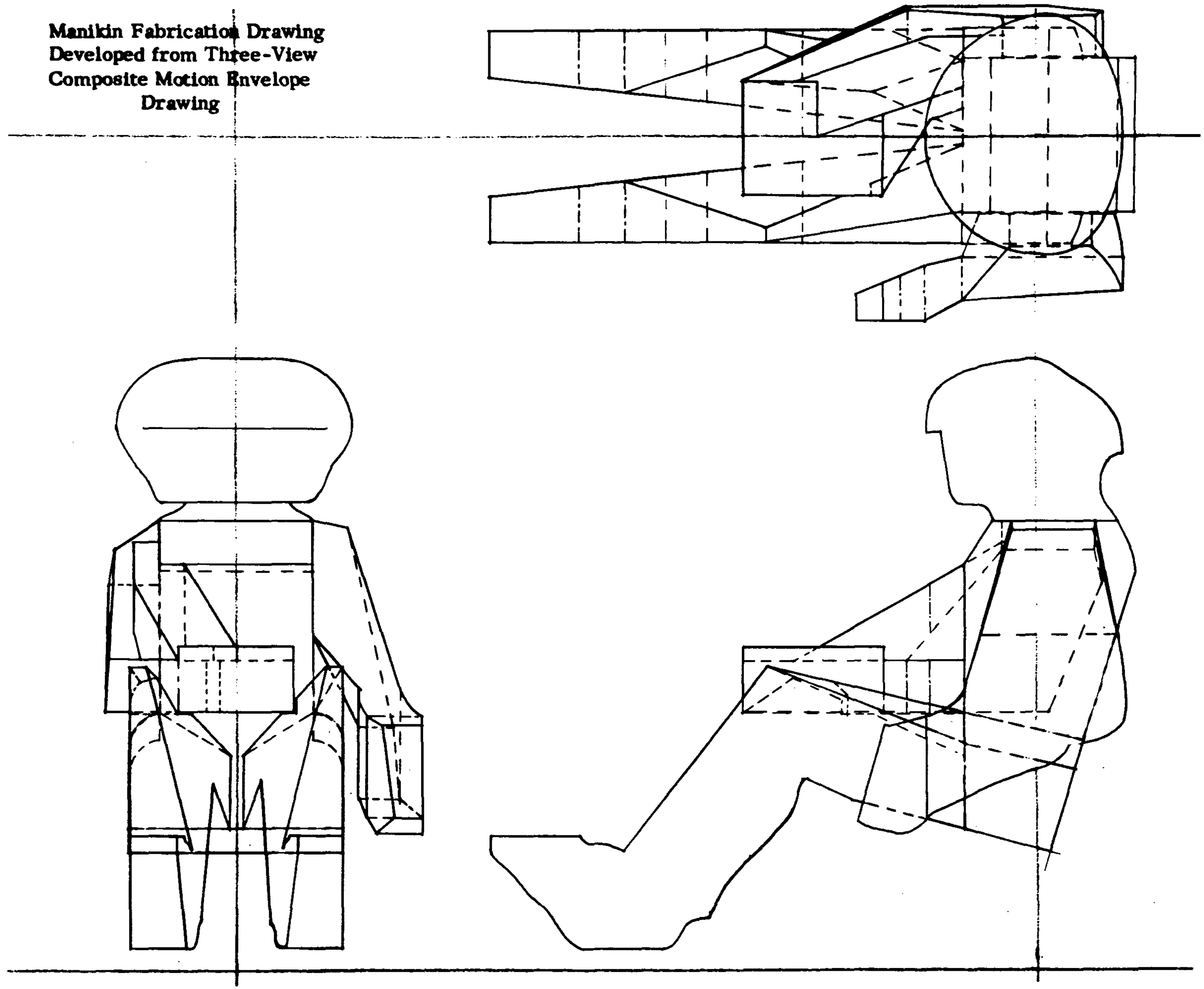


Fig. 19. MANIKIN FABRICATION DRAWING

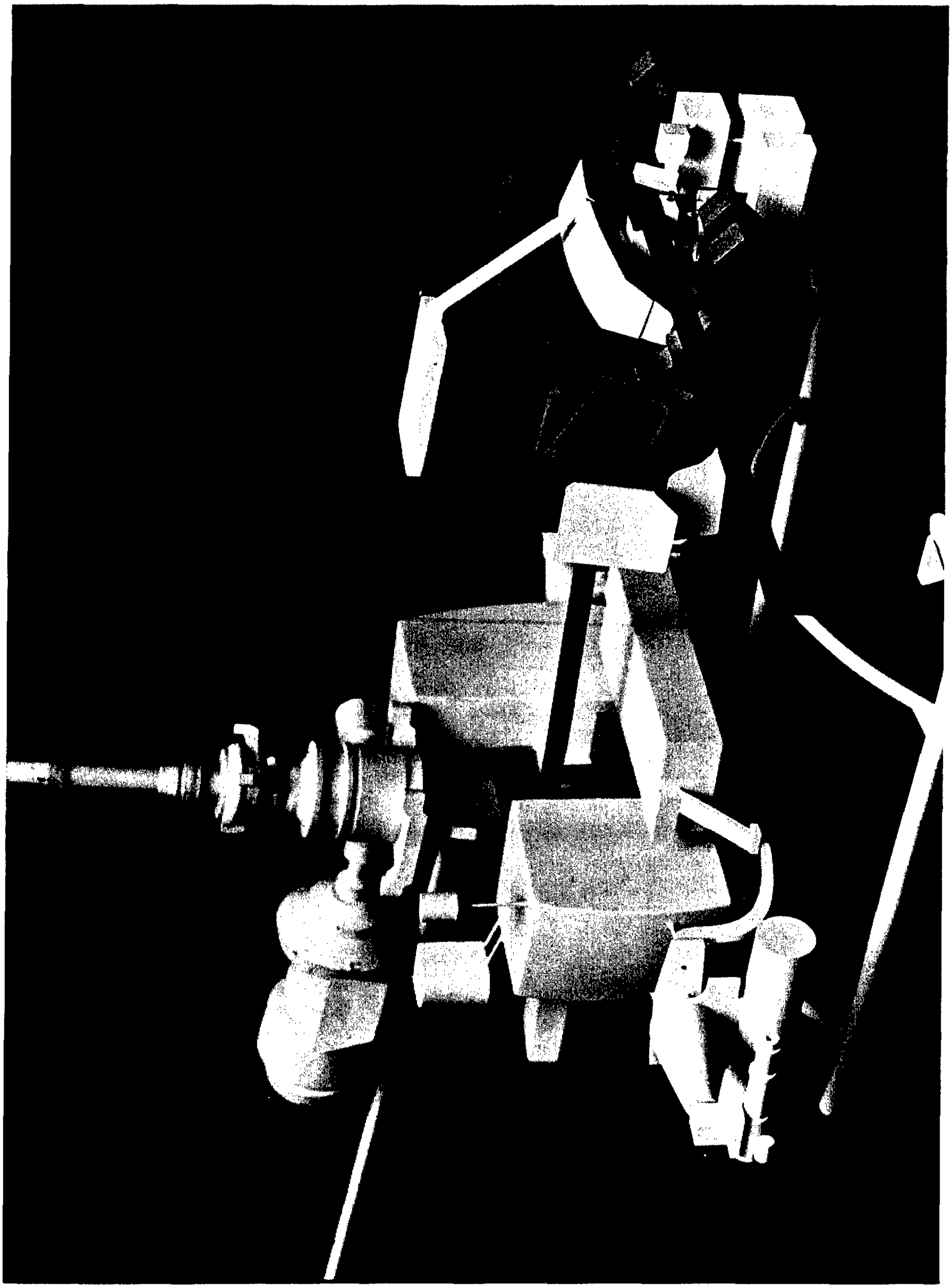


Fig. 20. VIEW OF UH-1C 1/10th SCALE MODEL WITH PILOT AND COPILOT MANIKINS REPRESENTING FUNCTIONAL MOTION ENVELOPES

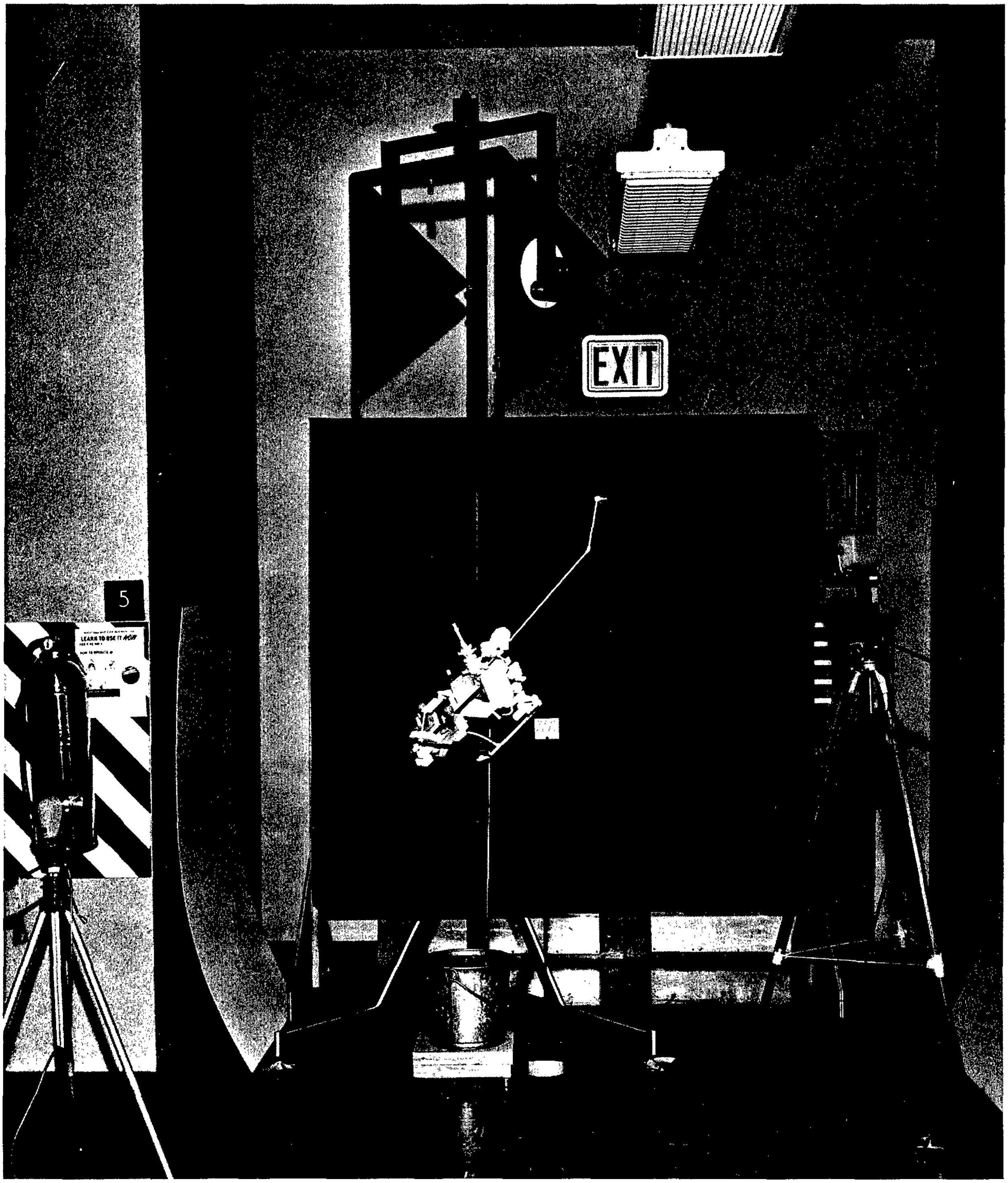


Fig. 21. ONE TENTH SCALE MODEL OF UH-1C HELICOPTER HANGING FROM ADJUSTABLE STAND (The pail below is filled with oil which provides viscous damping to the model when photographed.)

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(2) Combinatorial geometry/computer model technique.

An alternative method used to develop the penetration probability values utilizes combinatorial geometry. Basically, combinatorial geometry is a method of representing, in a computer, a complex, three-dimensional structure in terms of sums, differences and intersections of relatively simple bodies such as spheres and cylinders. The representations are geometric locations of simple bodies and their dimensions plus a series of equations defining each particular region of the structure in terms of these bodies.

The total geometric and functional description of the three-dimensional aircraft components and crew motion envelopes, once prepared for the computer, could present highly accurate data for the penetration probability values P(p) in this parameter. Further information may be obtained in reference MAGI-6701: A Geometric Description Technique for Computer Analysis of Both the Nuclear and Conventional Vulnerability of Armored Military Vehicles (Mathematical Applications Group, Inc., 1967).

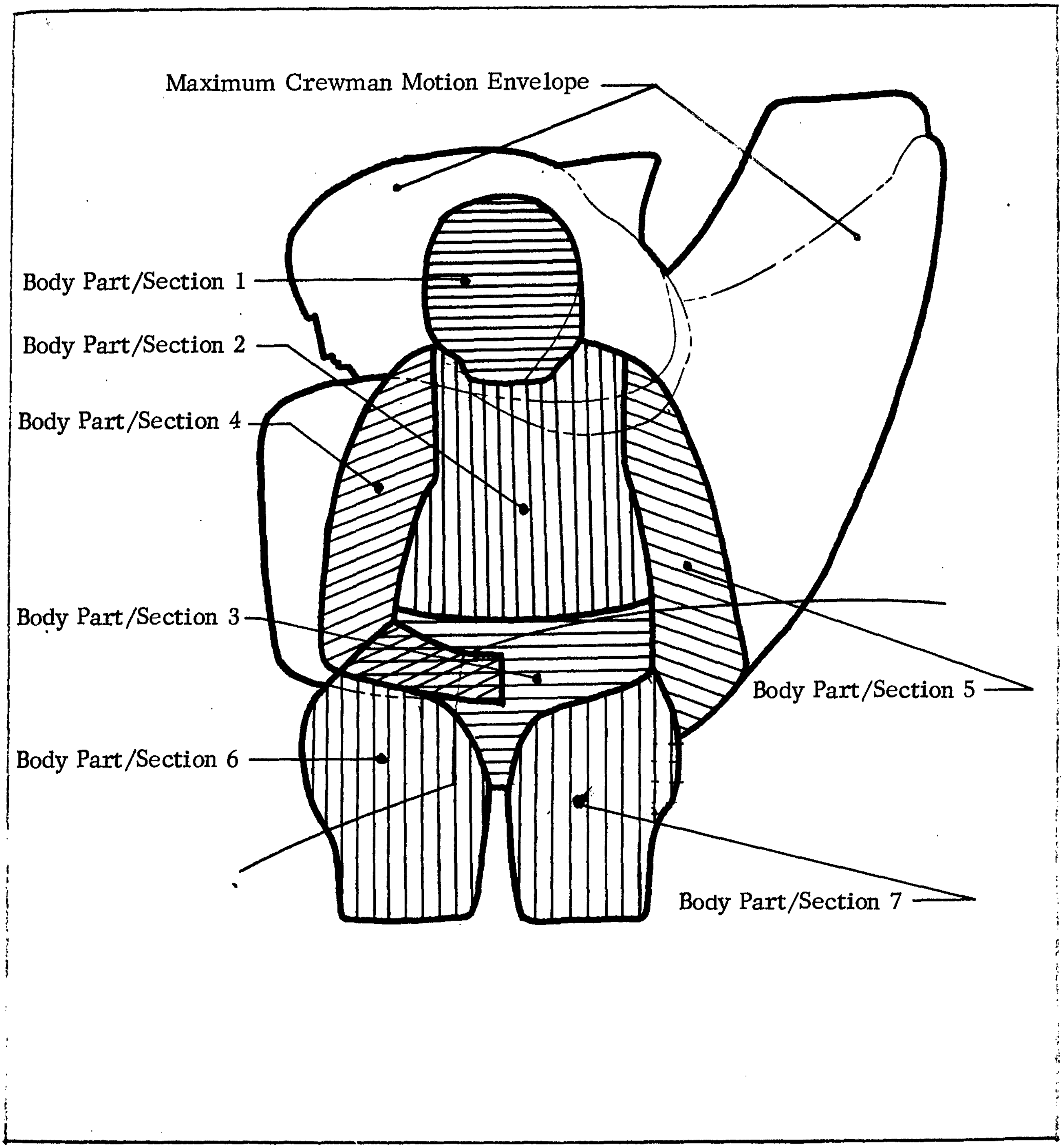
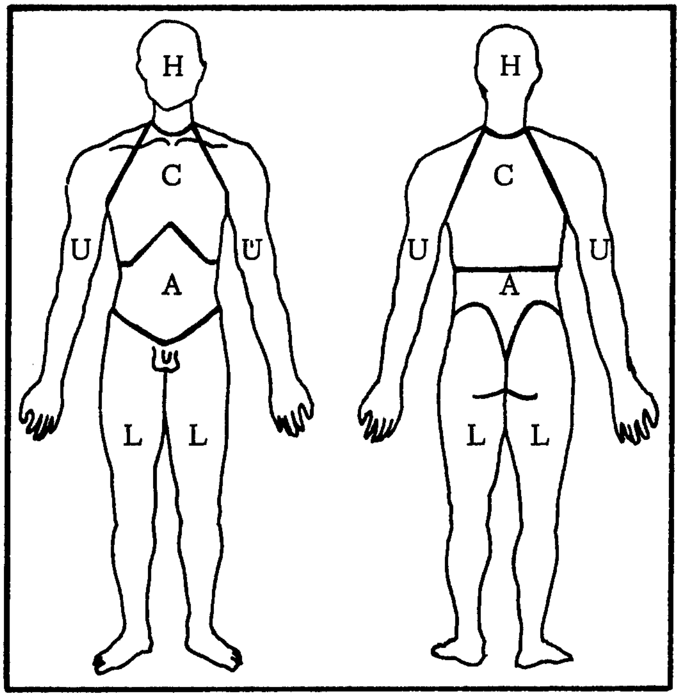


Fig. 22. CRITICAL (90% time) MOTION ENVELOPE SHOWN WITHIN MAXIMUM MOTION ENVELOPE

P(i) - The probability of hitting a particular body part, i, in a particular section of the crewman motion envelope. A maximum crew motion envelope is developed for each crewman. From this maximum motion envelope a critical (90 percent of the time) motion envelope is developed which contains only those positions held by the crewman for most of the critical mission time (Fig. 22). Note: It is this critical motion envelope that is used in either the 3-D model or the computer model mentioned in the previous section. With this critical 90 percent time motion envelope, it is assumed that a specific body part, i, is always contained in its specific envelope section. Assuming this, the mathematical expression P (i) indicating the probability of hitting a particular body part, i, in its particular section of the motion envelope will always have a probability value of one.

The use of this critical 90 percent time envelope insures that when a crewman's "total protection need" is computed and an armor system is developed to cover that need, no armor material/weight is wasted protecting a section of the crew station that rarely contains any of the crewman's vital body parts.



The regions of the body as
demarcated according to the
description in the text

symbol	region	percent of total body area
H	head and neck	12
C	chest	16
A	abdomen	11
U	upper extremities	22
L	lower extremities	39

Fig. 23. BODY REGIONS
(Taken from the Surgeon General's Report on Wound Ballistics, 1962.)

P(k) - The probability of kill of a man by body part. The probability of kill given a hit is based on the percentage of soldiers who die after being wounded. Existing information is very limited with respect to the number of deaths resulting from wounds caused by specific rounds. Because of the format in which it was presented, information derived from the World War II battles at Bougainville (Surgeon General's Report, 1962) was chosen as a basis for estimating P(k). The Bougainville data categorizes wound fatalities in terms of projectile source (rifle, mortar, machine gun, etc.) and seven main body parts (Fig. 23).

a. The statistics shown in Table 6 point out some of the parameters involved in the "Is a hit a kill?" question. The body area is obviously highly significant but is not the only factor to be considered. Eighth AF statistics appear to indicate the ameliorating effect of timely medical aid in wounds of the head and thorax, as well as perhaps indicating differences in wounding projectile and environment where it is sustained. Advances in medical technology can be assumed to have decreased these World War II probabilities of kill, but it is assumed that advances have been such that they affect wound treatment uniformly rather than favoring a specific body area.

TABLE 6

Survey of Casualties*

Source	Sample Size		Head	Thorax	Abdomen	Arms	Legs
Bougainville Campaign	1788	Hit	384	231	114	320	407
		Kill	144	87	48	1	14
		Percent	37.5	37.7	42.1	.3	3.5
New Georgia-Burma Campaign	369	Hit	74	63	25	63	83
		Kill	32	32	11	1	2
		Percent	43.2	50.8	44.0	1.6	2.4
Ground Combat Averages:			38.4	40.5	42.4	0.5	3.4
8th AF	1117	Hit	221	38	17	247	428
		Kill	39	11	7	1	9
		Percent	17.6	28.9	41.2	.4	2.1
	1553	Hit	327	100	51	447	628
		Kill	69	37	23	65	61
		Percent	21.1	37.0	45.1	14.5	9.7
Overall Average:			28.4	39.4	43.0	6.3	5.6

* Surgeon General's Report on Wound Ballistics, 1962.

b. Percentage kill by body part:

The abdomen, thorax and head should have an extremely high priority for armor based on the probability of death given a hit.

Abdomen

The abdomen's hit-kill probability never falls below 40 percent in the sample of approximately 5,000 casualties.

Head and thorax

The statistics for head and thorax are not so consistent but still have "overall" averages of 28.4 and 39.4 percent respectively. The difficulty here is believed to lie in the 8th AF data -- where, for instance, a casualty could be caused by plexiglass splinters in the face. In ground combat wounds are generally missiles or fragments which, of course, are much more serious wounding agents. For this reason, the ground combat figures have been chosen as the figures coming the closest to simulating combat in Vietnam. (The 8th AF figures represent casualties caused in an "environment of fire" much different from Bougainville and New Georgia.)

Arms and legs

The arms and legs had ground combat hit-kill probabilities of 0.5 and 3.4 percent respectively -- quite significantly lower than even the "overall average" figure for the head (which goes to a hit-kill probability of 38.4 percent when only ground combat figures are considered).

Tabulation of total hit probabilities

The final hit-kill probabilities for ground combat are therefore:

Head	38.4 percent
Thorax	40.5 percent
Abdomen	42.4 percent
Arms	0.5 percent
Legs	3.4 percent

SUMMARY AND DISCUSSION OF "PROTECTION NEED" MATRICES

The product of the four vulnerability parameters will produce a number "n" for each body part and direction combination using the general formula:

$$n = P\ (h\ p\ i\ k) = P(h)\ P(p)\ P(i)\ P(k)$$

These body part n's or "protection need" numbers are listed in a "protection need" matrix and presented as the primary output of this second phase.

This matrix is used to determine for each crewman the body parts to be protected from a given direction. The highest "n" values in the matrix will indicate those body parts having the highest "protection need." Protective armor may then be placed, based on the "need" ranking. When unlimited armor weight is available, each body part could be given maximum protection. When a limited amount of armor weight is available, only those body parts having high kill probabilities would be considered, starting with those body parts having the highest "n" for each direction and protecting these first. With this done, the next highest n's would be considered and so on until the armor weight available (as indicated in Phase I) has been expended.

As it currently stands, the input data needed for each parameter is inadequate or in some cases non-existent. Because of this the following assumptions are made:

$P(h) = 1$ (hit probability) $P(i) = 1$ (body-part hit probability)

$P(p) = 0$ or 1 (penetration probability) $P(k) = 0 \leq 1$ (kill probability)

The only P value that will vary is the probability of kill, P(k), value. Based on the above assumptions, the "protection need" matrix generated in Phase II would be similar to the following example (Table 7).

TABLE 7

"Protection Need" Matrix Example 1

Direction of Fire		Body Part Number						
Azimuth	Elevation	1	2	3	4	5	6	7
0.0	0.0	.38	.00	.00	.00	.00	.00	.03
22.5	57.5	.38	.40	.42	.00	.00	.03	.00
90.0	90.0	.00	.00	.00	.01	.00	.00	.03
180.0	112.5	.38	.40	.42	.00	.01	.03	.00

When more accurate input data becomes available, the four vulnerability parameter values will then become:

P(h)	$0 \lesssim P(h) \lesssim$	P(i)	= 1
P(p) = 0 or 1		P(k)	$0 \lesssim P(k) \lesssim 1$

Under these conditions the "protection need" matrix would take the following form (Table 8).

TABLE 8

"Protection Need" Matrix Example 2

Direction of Fire		Body Part Number						
Azimuth	Elevation	1	2	3	4	5	6	7
0.0	0.0	.38	.00	.00	.01	.00	.03	.01
22.5	57.5	.32	.20	.19	.00	.01	.00	.02
90.0	90.0	.29	.32	.29	.00	.00	.02	.00
180.0	112.5	.21	.21	.03	.01	.00	.01	.03

The matrix presented in Table 8 now contains a more realistic distribution of "n" values; i.e., "n" no longer assumes the same values as P(k). Instead, each "n" now reflects the influence of variations in both P(h) and P(k). The values of P(p) and P(i) are still equal to 1. Note: where P(p) = 0, the "n" automatically assumes a value of "0" in the matrix.

Example:

A section of the UH-1C pilot/copilot "protection need" matrix is presented in Table 9. (See Appendix C for the complete UH-1C "Protection Need" Matrix.) This matrix is based on the assumptions used to generate Table 7 above:

P(h) = 1	P(i) = 1
P(p) = 0 or 1	$P(k) = 0 \lesssim 1$

Hence, the numbers in the matrix reflect the hit-kill probability values P(k) assigned to specific body parts as taken from the Surgeon General's report.

Body Part	Number	Hit-Kill Probability from SGO
Head	1	38.4 percent
Thorax	2	40.5 percent
Abdomen	3	42.4 percent

The crew's arms and legs were not considered in this matrix because of their low hit-kill probabilities.

By describing each crewman's "protection need," this matrix forms a major portion of the data required to initiate Phase III of the guideline which presents a methodology for developing and evaluating aircrew armor systems.

TABLE 9

Aircrew "Protection Need" Matrix

Aircraft: UH-1C
Crewman: Pilot

Direction of Fire		Crewman Body Part Number							
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4	40.5	42.4				
	315		38.4	40.5	42.4				
	292.5		38.4	40.5	42.4				
	270		38.4	40.5	42.4				
	247.5		38.4	40.5					
	225		38.4						
	202.5		38.4						
+	180		38.4		42.4				
	157.5		38.4						
	135		38.4						
	112.5		38.4	40.5					
	90		38.4	40.5	42.4				
	67.5		38.4	40.5	42.4				
	45		38.4	40.5	42.4				
	22.5		38.4	40.5	42.4				
45	0		38.4	40.5	42.4				
	22.5		38.4	40.5					
	45		38.4	40.5					
	67.5		38.4	40.5					
	90		38.4	40.5					
	112.5		38.4	40.5					
	135		38.4						
	157.5		38.4						
−	180		38.4						
	202.5		38.4						
	225		38.4						
	247.5		38.4	40.5					
	270		38.4	40.5					
	292.5		38.4	40.5					
	315		38.4	40.5					
	337.5		38.4	40.5					

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PHASE III

ARMOR SYSTEMS DEVELOPMENT AND EVALUATION METHODOLOGY

OVERVIEW

Current methods of designing and evaluating aircrew armor systems required improvement. A standardized approach was needed that would permit systematic identification of the various system parameters pertinent to armor systems design and encourage the application of detailed human engineering design criteria during the development activity.

One solution lies in taking advantage of computer graphics techniques which can visually integrate the aircraft and human input variables associated with armor systems development. This third phase presents a design approach which utilizes a computer-directed drawing instrument to expand present armor systems design and evaluation capabilities (Fig. 24).

INPUT DATA

When an integrated aircrew armor system is generated, tradeoffs must be made between the aircraft's system, mission and performance requirements, the aircrew's performance requirements, and aircrew anthropometric data. Consequently, in the initial phases of the study, an effort is made to identify these aircraft and human variables and to index the specifics in each as a logical first step in formulating a standardized armor design/evaluation methodology (Fig. 25). Phases I and II of the guideline require a systematic investigation of these variables to determine:

1. The feasibility of adding armor to an existing aircraft.

2. The aircrew's "protection need" within the aircraft system.

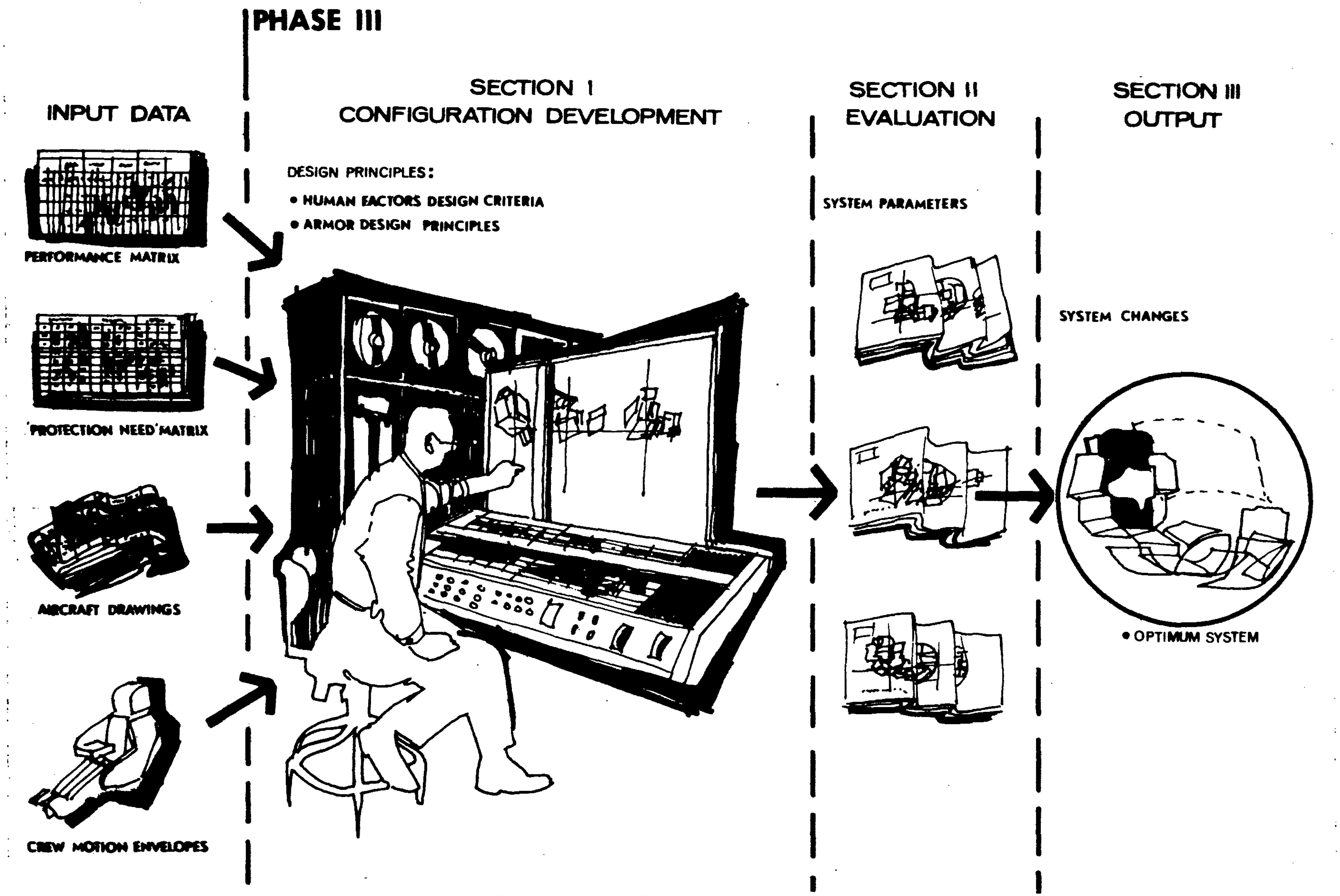

Fig. 24. PHASE III FLOW CHART

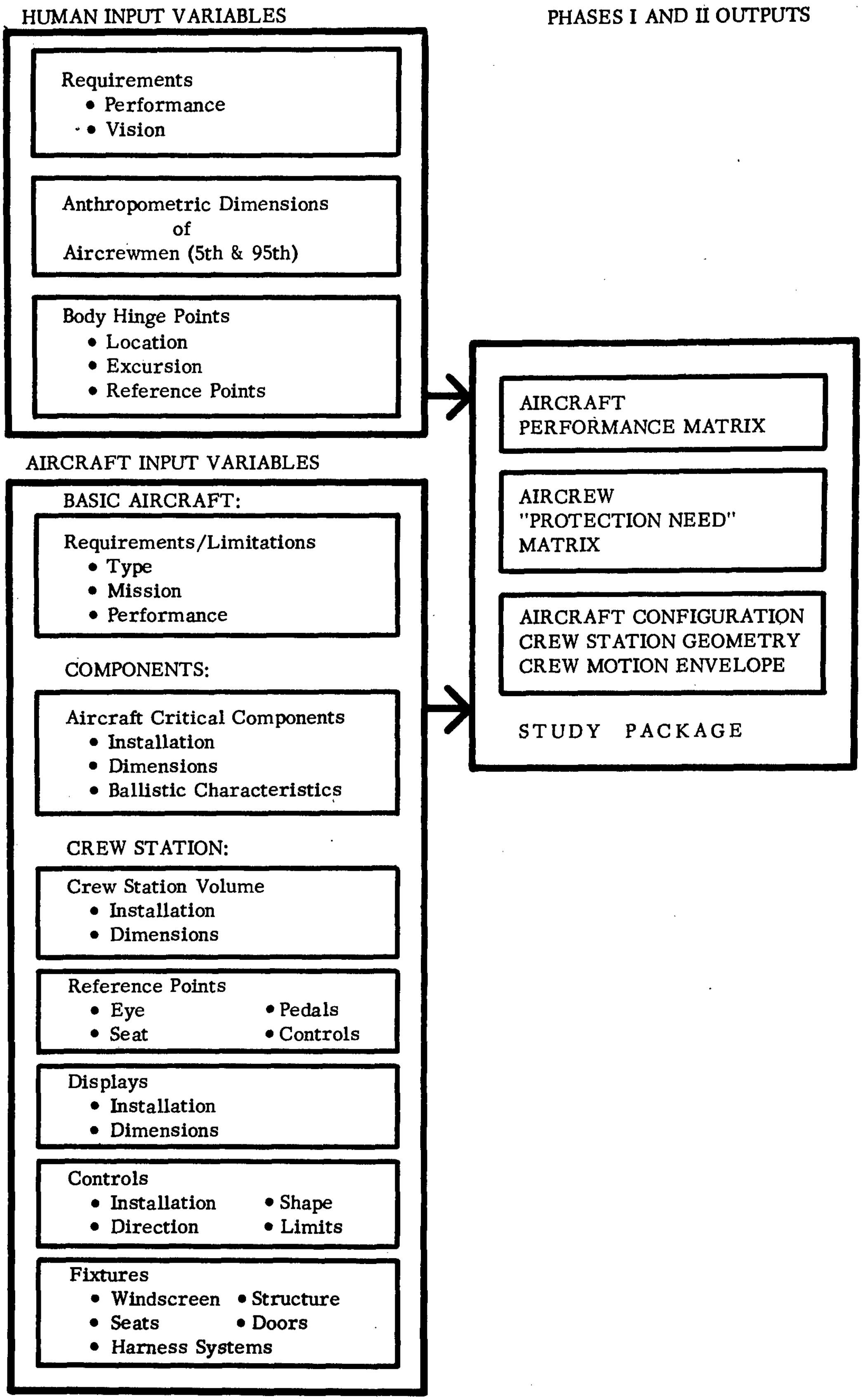

Fig. 25. STUDY INPUT VARIABLES

The following factors constituted the input data necessary to initiate Phase III:

1. Aircraft Performance Matrix

In any aircraft there is a limit to the amount of weight that the system can tolerate. For existing aircraft the limit for armor weight is established from a performance matrix similar to that developed in Phase I of the guideline. For proposed aircraft, a specific amount of weight is allotted to aircrew protection in the early design weight and balance studies. In either case, this weight limit is one of the most critical factors to be considered in the design of aircrew armor systems since exceeding this limit would seriously affect the aircraft's required payload, airspeed, flight endurance and takeoff/hover capability.

Example:

The UH-1C performance matrix (Table 10) developed in Phase I of the guideline is a table of values that shows, for the study aircraft, the various armor weights which may be added to the system and the endurance time associated with each armor weight addition. The sample performance matrix is the result of computation using a UH-1C aircraft at 8628.5 lbs. takeoff gross weight. Note: This configuration is not necessarily the standard used in Vietnam since it does not include certain mission essential equipment and personnel currently employed on UH-1C aircraft (i.e., two door gunners/M-30 weapon systems).

2. Aircrew "Protection Need" Matrix

The aircrew "protection need" matrix is a series of tables which indicate, for each crewman in a particular aircraft, the various body parts requiring protection. The highest "n" values in the matrix will designate those body parts having the highest "protection need."

Example:

The following UH-1C example "protection need" matrix (Table 11) is based on the UH-1C aircraft configuration and crew motion envelopes shown in Figure 26. For the complete UH-1 "Protection Need" Matrix, see Appendix C.

TABLE 10

UH-1C Performance Matrix Example

Armor Location/W_A		W_F	Fuel Payload W_{F_B}	W_{F_U}	Flight Endurance
58.5	100 lbs.	1,624.3 lbs.	0 lbs.	1,624.3 lbs.	3.6 hrs.
	200	1,524.3	0	1,524.3	3.4
	300	1,424.3	0	1,424.3	3.2
	400	1,324.3	0	1,324.3	2.9
	500	1,224.3	0	1,224.3	2.7
	600	1,124.3	0	1,124.3	2.5
	700	1,024.3	0	1,024.3	2.3
	713	1,011.3	2.75	1,008.5	2.2
	720	1,004.3	42.5	961.8	2.1
	730	994.3	99.3	894.9	1.9
	740	984.3	156.2	828.1	1.8

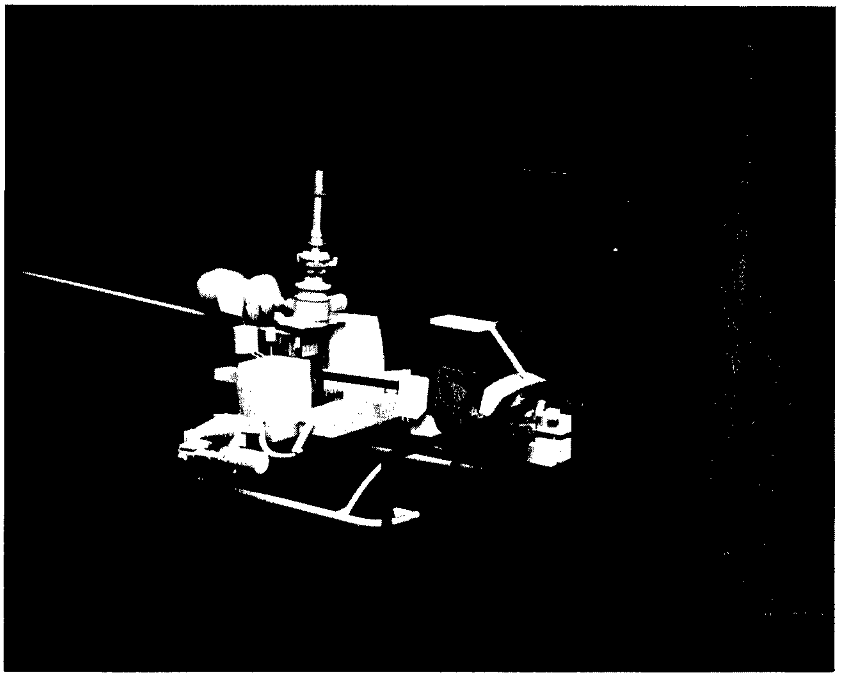

Fig. 26. UH-1C AIRCRAFT/CREW STUDY MODEL

TABLE 11

Example of Aircrew "Protection Need" Matrix

Aircraft: UH-1C
Crewman: Pilot

Direction of Fire			Crewman Body Part Number						
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4	40.5	42.4				
	315		38.4	40.5	42.4				
	292.5		38.4	40.5	42.4				
	270		38.4	40.5	42.4				
	247.5		38.4	40.5					
	225		38.4						
	202.5		38.4						
	180		38.4		42.4				
	157.5		38.4						
	135		38.4						
	112.5		38.4	40.5					
	90		38.4	40.5	42.4				
	67.5		38.4	40.5	42.4				
	45		38.4	40.5	42.4				
	22.5		38.4	40.5	42.4				
45	0		38.4	40.5	42.4				
	22.5		38.4	40.5					
	45		38.4	40.5					
	67.5		38.4	40.5					
	90		38.4	40.5					
	112.5		38.4	40.5					
	135		38.4						
	157.5		38.4						
	180		38.4						
	202.5		38.4						
	225		38.4						
	247.5		38.4	40.5					
	270		38.4	40.5					
	292.5		38.4	40.5					
	315		38.4	40.5					
	337.5		38.4	40.5					

3. Aircraft/Crew Station/Crew Motion Envelopes Study Package

This study package consists of engineering drawings (inboard profiles) of the aircraft including:

Components offering ballistic protection to the crewmen.

Crew-station geometry (controls, seats, panels, brackets, consoles, displays, etc.)

Crew motion envelopes strictly related to critical mission tasks and functions.

Crew station water and butt line information.

These drawings form the basis for the armor configuration design study conducted in this phase. If these drawings are preliminary in nature (proposed aircraft), the armor systems evolved around them may require updating if major system changes are made during the aircraft's development stage (i.e., major crew station changes or relocation of engine, fuel cells, etc.).

Example:

UH-1 inboard profile drawings (Figs. 27a & b). These engineering drawings define the components offering ballistic protection and the exact crew station geometry. The drawings were updated to include the current aircrew armored seats and the 5th/95th percentile crew motion envelopes developed in Phase II.

Aircrew motion envelopes. The 5th and 95th percentile pilot's critical and non-critical motion envelopes were drafted and included in the UH-1 inboard profiles. Figure 28 illustrates this final composite motion envelope.

Water and butt line data (Figs. 29a & b). The water and butt line drawings of the UH-1 crew station area were developed to facilitate the placement of armor panels on the aircraft structure.

In addition to this data, the following section, "Design Principles and Practice," is applicable during aircrew armor system development and evaluation. A complete listing of detailed technical characteristics and materiel requirements for aircrew protective armor may be found in the following references. (Bailey, 1968; Rodzen, et al, 1967; U. S. Army Materiel Command, 1965; U. S. Army Natick Laboratories, 1966). Detailed human engineering design criteria, consisting of human dimensions, ranges, tolerance, and specific data which are essential in the development of armor systems may be found in AFSC DH1-6 System Safety Design Handbook (Hq, USAFSC, 1967) and Human Engineering Guide to Equipment Design (Morgan, Cook, Chapanis, Lund, 1963).

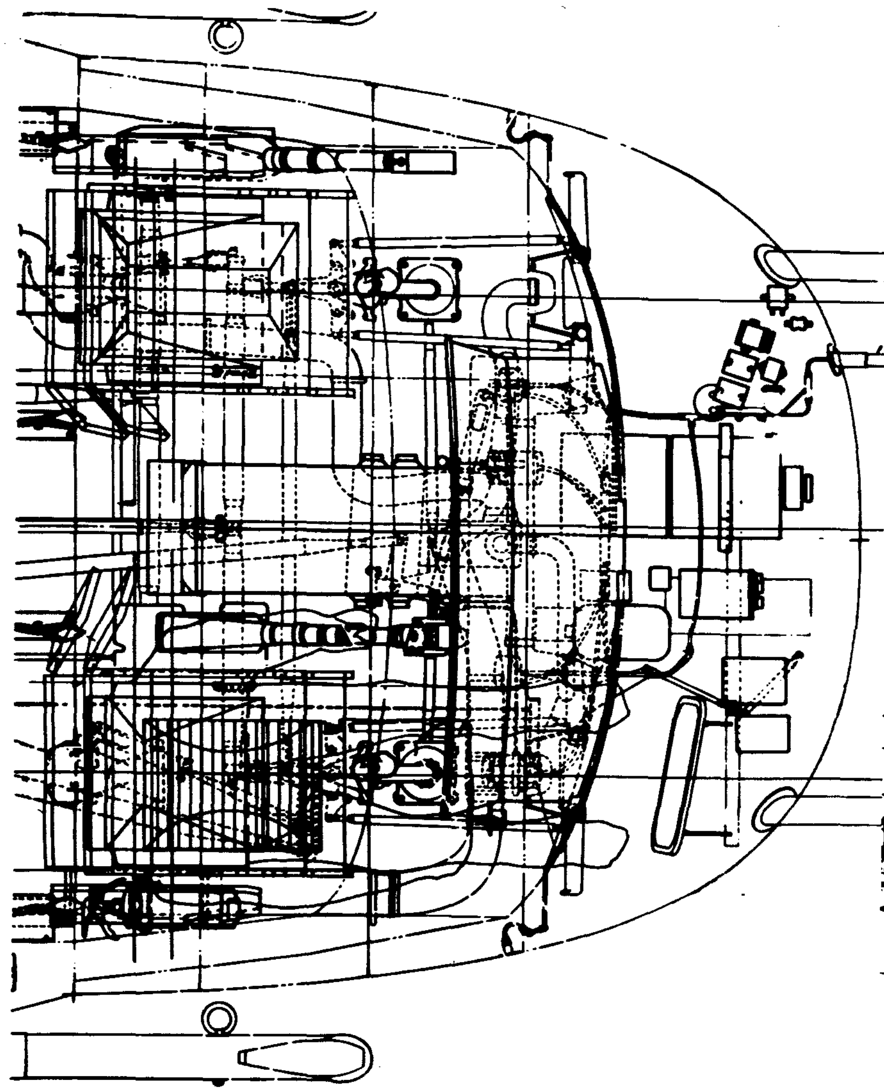

Fig. 27a. UH-1 INBOARD PROFILE/TOP VIEW

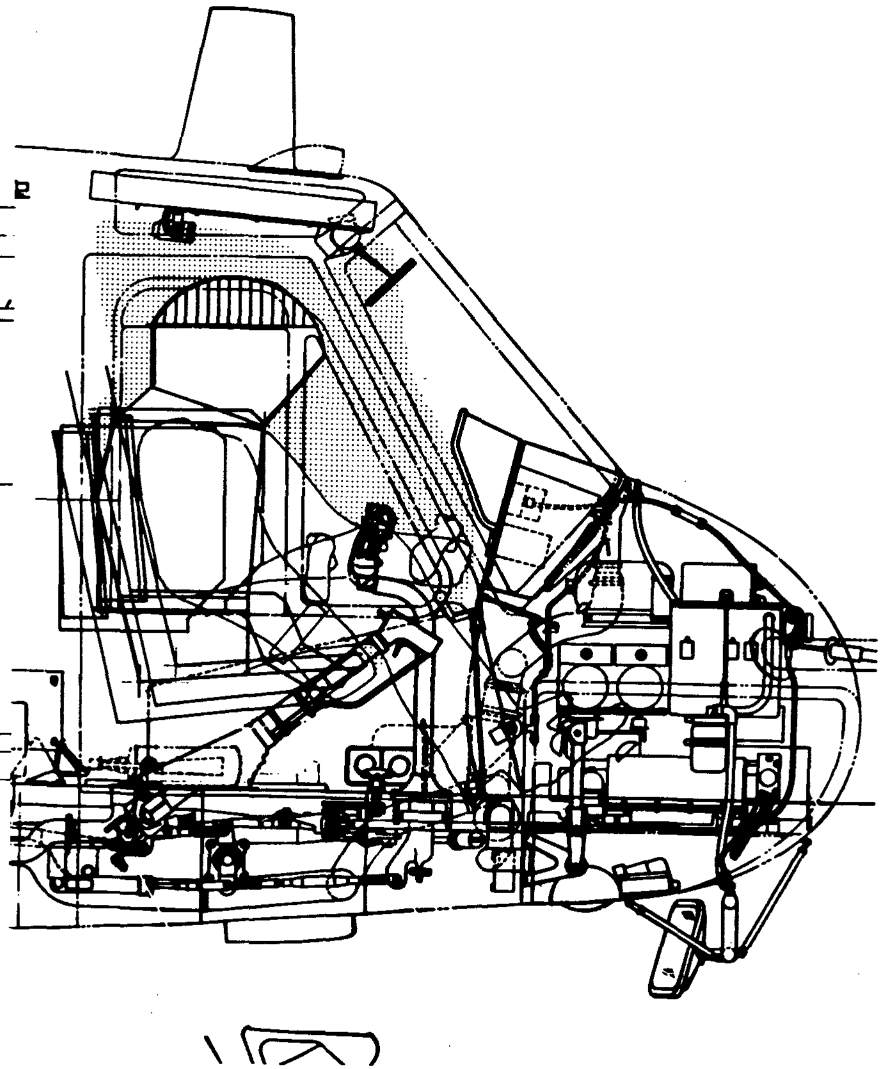

Fig. 27b. UH-1 INBOARD PROFILE/SIDE VIEW

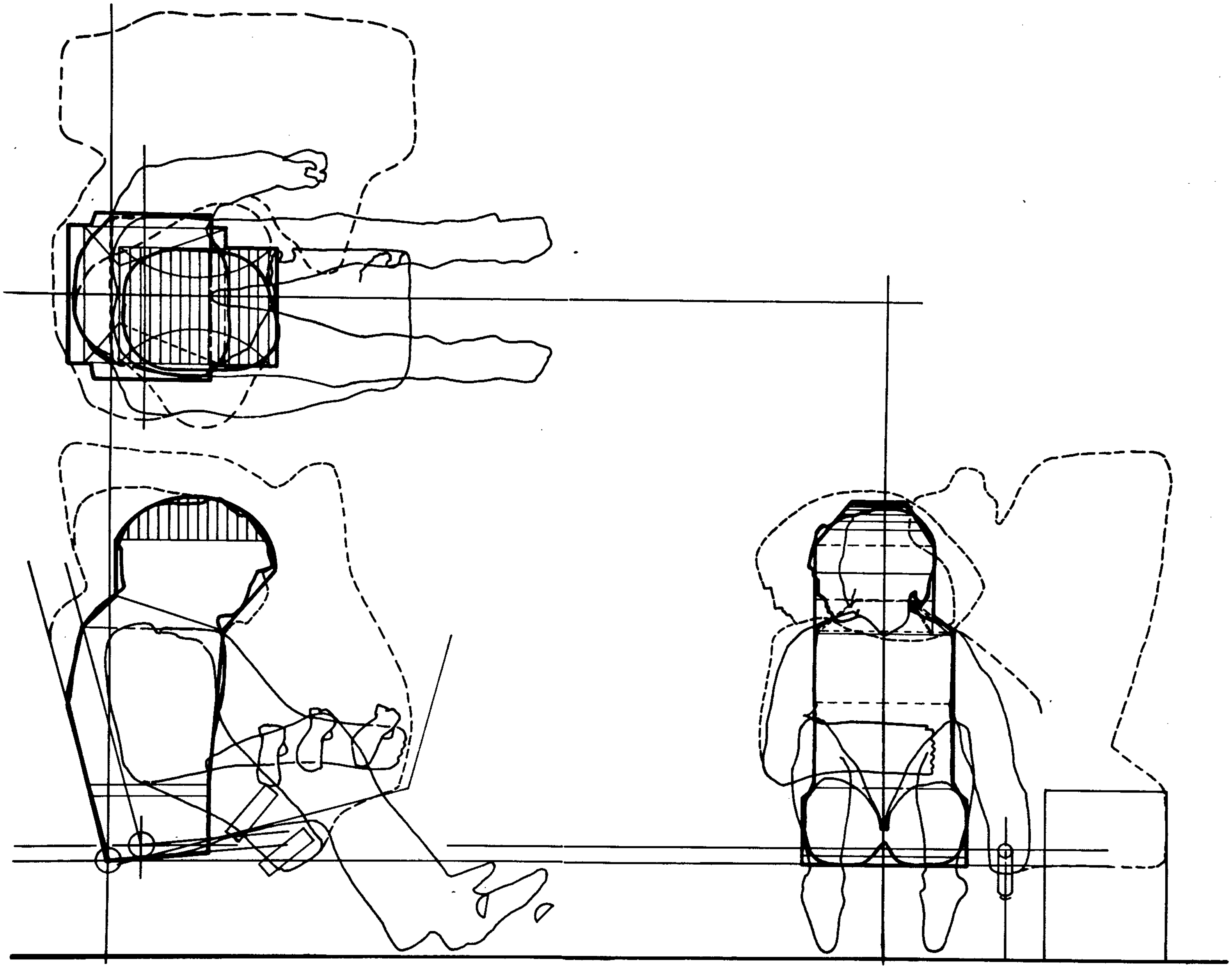

Fig. 28. COMPOSITE CREW MOTION ENVELOPE

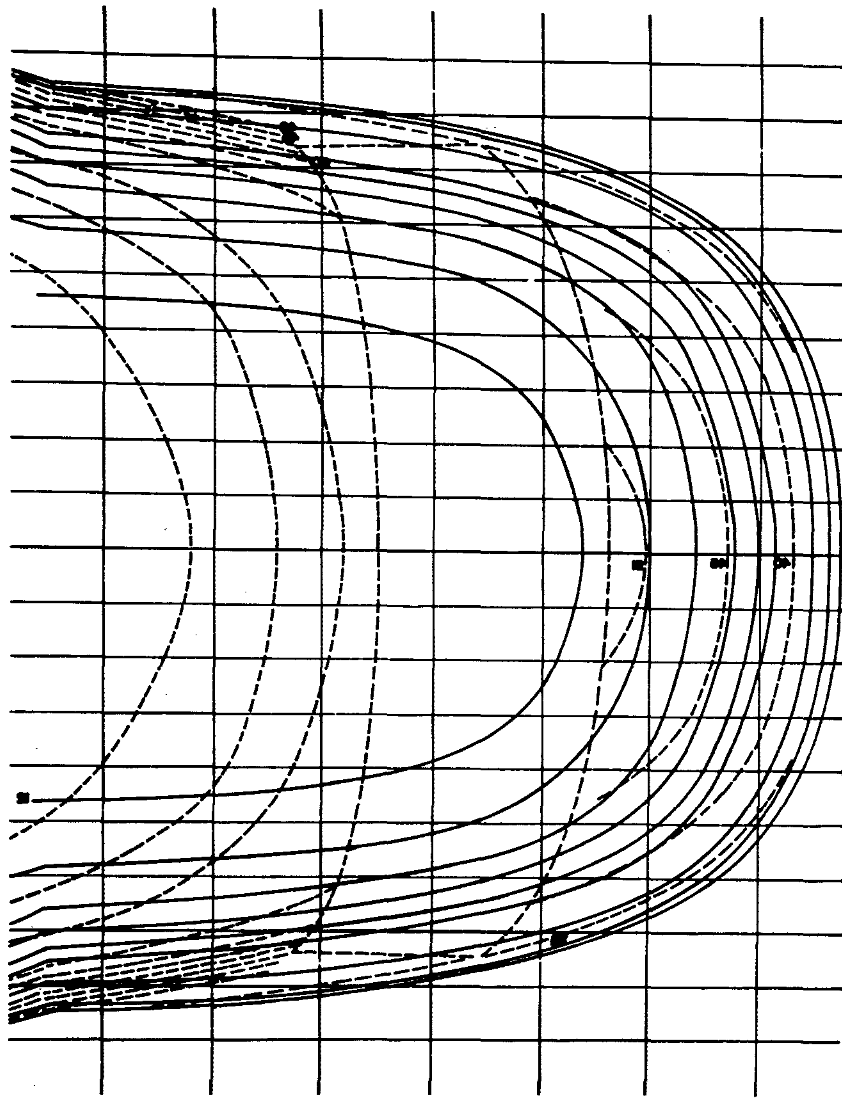

Fig. 29a. UH-1 WATER AND BUTT LINE DRAWING/ TOP VIEW

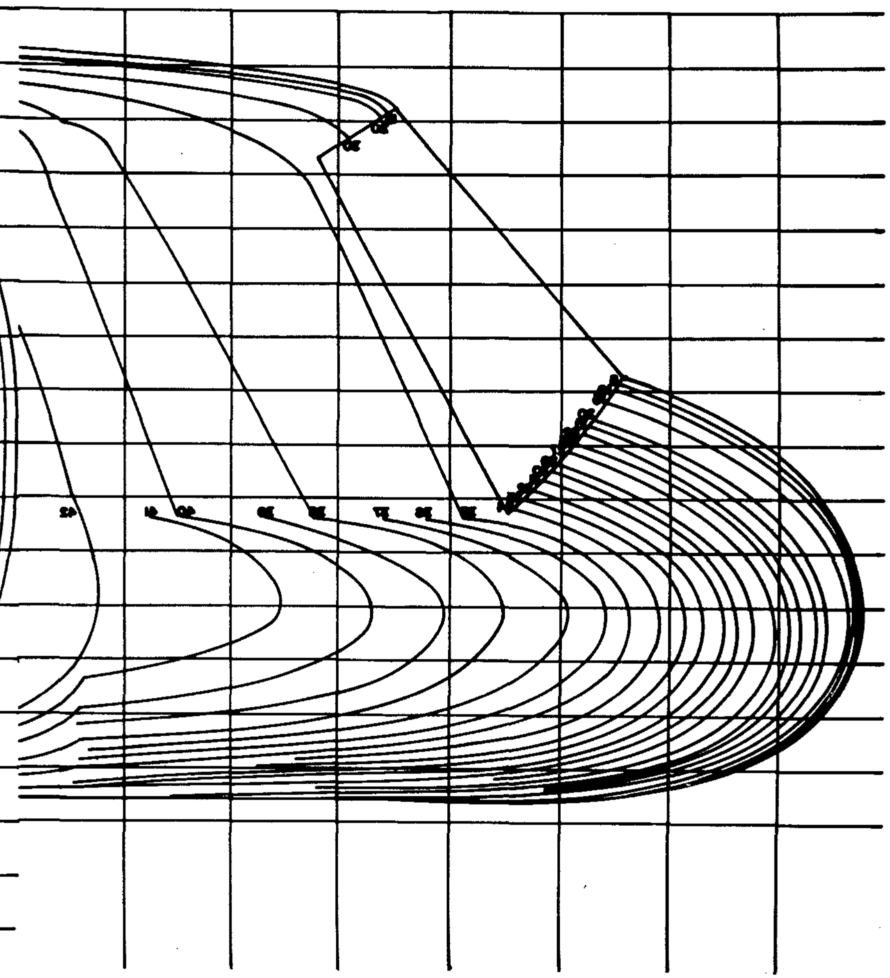

Fig. 29b. UH-1 WATER AND BUTT LINE DRAWING/ SIDE VIEW

General Armor Design Principles

The term "aircrew armor" as used above is meant to be a generic expression encompassing any one or combination of three categories of armor systems used to protect crewmen from small arms fire (30 cal, 50 cal, 14.5mm).

Body Armor: Those pieces of armor material, in kit form, which are worn on various portions of the aircrewman's body.

Seat Armor: Those pieces of armor material integral with or mounted (in kit form) to the aircrew seats.

Aircraft Armor: Those pieces of armor material integral with or mounted (in kit form) to the aircraft structure in or near the crew station.

As indicated above, aircrew protection can be achieved by utilizing armor kits, by making armor an integral part of the aircraft, or a combination of both. An armor kit allows the protection to be increased or decreased as the specific situation dictates. Integral armor reduces the overall weight of the aircraft when compared to the same protection using kits, but removal of integral armor (maintenance, etc.) would likely require major modification to the aircraft. A composite of integral armor and kit armor yields the optimum solution in terms of flexibility, individual crew protection, and total system weight.

Since complete coverage of the human body is neither feasible nor particularly required, placement of the protective material should be "preferential," i.e., cover only those body areas having the highest priority ("n" value), starting with the highest and working down.

Weight and complexity of the armor system must be kept at a minimum. Methods of accomplishing this include:

Early-design mission analysis to determine the relative merits between aircraft-installed or personnel-worn armor for various crewmembers.

Use of ballistic materials in component or basic aircraft structure.

Utilizing aircraft structure and components offering ballistic protection in conjunction with the armor system to reduce the amount of armor material used.

Armor systems should be compatible and integrated to minimize "protection overlap."

The closer the armor material is placed to the crewman, the less material is required to protect the same area. However, when the crew-station geometry is such that the aircraft structure and aircrew seat are inches apart (AAFSS, Cobra), the protection gained by placing the armor at the seat rather than in or on the aircraft structure may not be sufficient to offset the resulting crammed crew station conditions, control interference, etc.

Aircrew Armor Human Factors Design Principles

When aircrew armor systems are refined, tradeoffs must be made between crew comfort, tolerable weight, and area coverage. However, the crewman's ability to perform his critical mission tasks and functions is of prime importance and should not be compromised to gain added protective coverage.

Compatibility of the aircrew armor system with ejection, parachute harness and other emergency egress systems is of prime importance, AVLABS TR 67-22 (Turnbow, et al, 1967).

The aircrew armor system must be crashworthy as defined in AVLABS TR 67-22 (Turnbow, et al, 1967).

Human Factors Design Principles Related to Body Armor

Because of the configuration of the human body, any attempt to fit simple cylindrical armor shapes over these complex body shapes results in the introduction of severe pressure points and chafing. The use of anatomically shaped armor reduces overall weight, gives increased coverage and improved comfort by carrying the weight on the muscular portions of the body rather than the bony structure.

As body dimensions vary within a specific size range, adjustability of the body armor becomes more critical with increased wrap-around. This adjustability should allow for variations in body length, depth, breadth and girth.

The aircrew body armor carrier should be lightweight, yet rugged enough to support the armor weight under impact loading; otherwise the armor may break loose and cause body injury or it may reduce the effectiveness of the seat and seat belt or shoulder harness. Proper design results in beneficial crash effects in the form of improved crashload distribution on the body and resistance to localized penetration or crushing.

The armor carrier should be adequate, with cushioning between the armor and the body part.

The body armor should be easy to don and doff and should have an emergency quick-release capability.

The system must be consistent with crew vision standards, MIL-STD-850A (Department of Defense, 1967), and aircrew heat-stress limits, AR 705-15 C1 (Department of the Army, 1962).

The system must be compatible with normal individual clothing and ancillary equipment peculiar to the aircraft environment, AR 705-50 (Department of the Army, 1968a).

The armor system should provide maximum protection for the critical body parts of 5th through 95th percentile crewman as per USANLABS TR EP-150, "Anthropometry of Army Aviators" (White, 1961).

The armor system should have positive locking and unlocking systems when articulating armor pieces are used.

Adequate clearance and/or padding should be provided between the armor material and the crewman to allow for ballistic impact deformation.

The armor system should have a field installation and maintenance capability.

The armor system should be properly identified and marked with approved nomenclature, MIL-STD-783A (Department of Defense, 1966), to indicate direction of movement for proper operation when articulating pieces are used.

The armor system should not interfere with the normal and emergency egress controls.

The aircrew armor system should be compatible with the crew coordination and interaction requirements.

The armor restraining devices, fasteners, straps, buckles and closures require special attention to reduce any pad/armor disorientation or confusion between adjustment and quick-release straps, AR 705-5 (Department of the Army, 1968b).

The armor design methodology outlined in the following section utilizes a complex and detailed computer graphics technique as a tool for developing integrated aircrew armor systems. The effectiveness of this method, however, continues to depend upon the accuracy of the input data generated in Phases I and II and the creative application of the design principles and practice previously outlined.

SECTION I. CONFIGURATION DEVELOPMENT

Design Study Methodology

Through the use of a computer-directed drawing instrument, it is possible to visually integrate the aircraft, crew station and crew motion envelope data in three-dimensional form. As a design tool, the drawing instrument permits the extent of critical crew body-part vulnerability to be established from any direction and, utilizing the inherent passive protection in the aircraft system, to visually locate various armor configurations within the aircraft while adhering to crew performance requirements and human factors design criteria.

In addition, the drawing instrument provides the following advantages over current armor system design tools:

It is applicable in all stages of crew station/armor system development from concept development to existing aircraft.

It permits the total armor envelope required to protect each crewman to be described.

It permits rapid two- and three-dimensional visualization of armor system development.

It describes the protection afforded to all crewmen by an aircraft component or a particular section of armor, thereby indicating redundancy or overlap in an armor system.

It permits areas of crew/armor interference to be identified.

It produces results in a form applicable to design development decision.

It stimulates consideration of critical crew-motion envelopes, vision standards, wiring, ducting, control linkages, and current body/seat armor systems, while proposed armor systems are being developed and/or evaluated.

It provides a common reference with which to compare and evaluate the protection inherent in various armor configurations.

It produces repeatable results.

Computer-Directed Drawing Instrument Technique

Using the orthographic aircraft inboard profiles, which contain all the necessary dimensional information, accurate axonometric drawings of any part of these drawings can be made by the machine. When pertinent sections, lines, components and crew-motion envelopes are traced, this two-dimensional data is stored automatically in the drawing instrument's computer. With the proper controls adjusted to the desired station-point distance, subject azimuth, elevation, and scale, the computer converts the stored two-dimensional data into three-dimensional data and directs a pen on an XY board to plot the desired axonometric drawing.

Example:

If the computer is set to draw at 45° azimuth, -45° elevation, and a particular crewman and armor seat had been traced on the aircraft profile drawings, a third-view 45-45 axonometric drawing of this crewman and armored seat would appear on the XY plotter board (Fig. 30). The effectiveness of the armored seat can be determined from this direction by visually locating the crewman's critical body parts, protected or unprotected. By working back and forth between the inboard profile drawings and the axonometric view, the armor seat can be extended to fill a void; or if this is not feasible, the need for body armor or aircraft armor protection would be indicated.

With the computer-directed drawing instrument as a design tool, two basic approaches can be used to develop integrated aircrew armor configurations:

Develop engineering drawings of the aircrew's required armor envelope, protecting all vital body parts for all directions indicated. With the total armor envelope established, the actual armor configuration could then be developed by working back, eliminating armor related to those body parts and directions having low priority, until the system is within the armor weight limit specified. With the total armor envelope known, any future system modifications that would enhance the aircraft's payload capacity, or any breakthrough in armor material state-of-the-art can be quickly applied to the aircraft without a complete re-examination of the system.

Develop an armor system to protect only those body parts and directions having the highest priority until the specific armor weight limit is reached.

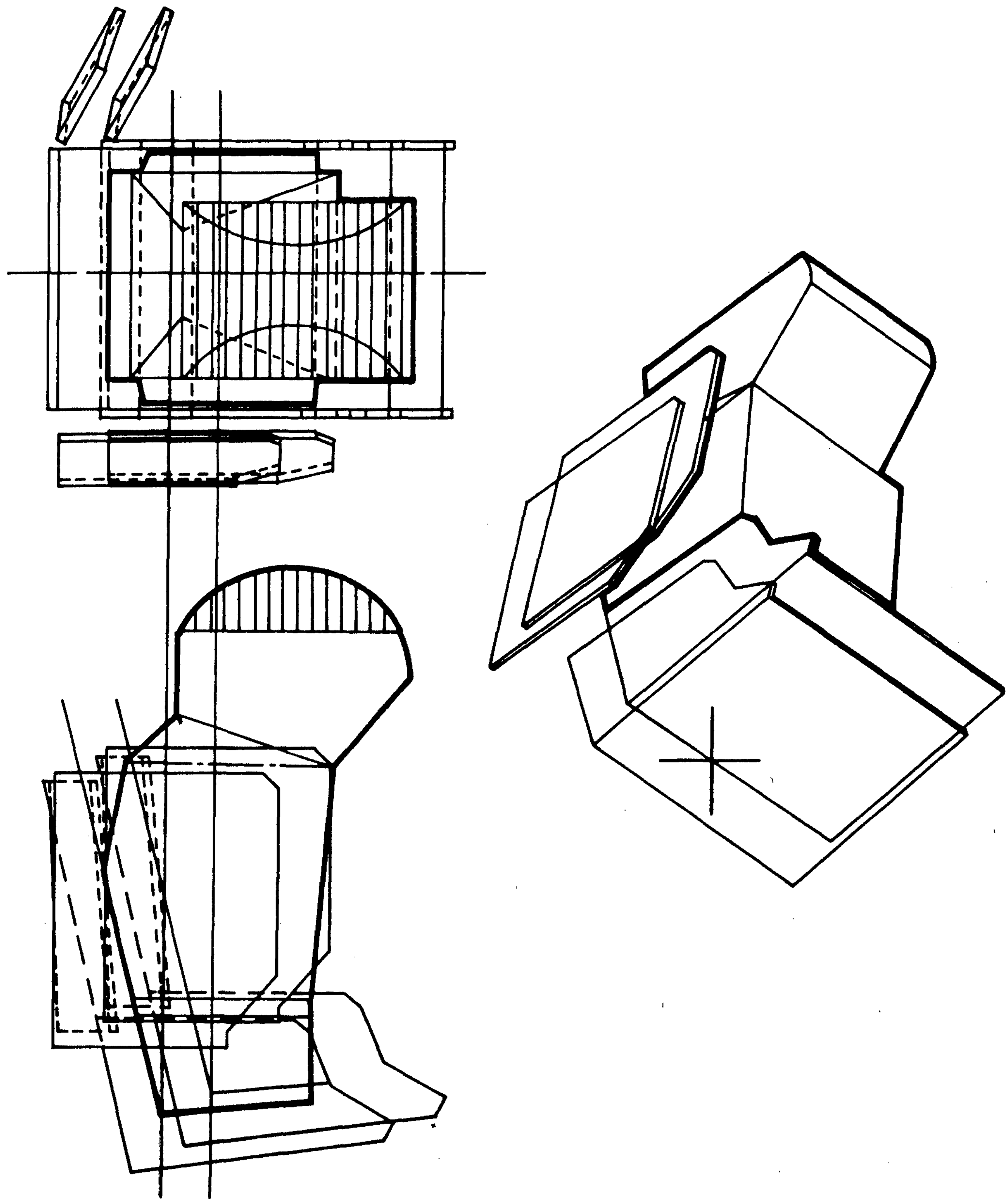

Fig. 30. COMPUTER-DIRECTED DRAWING INSTRUMENT TECHNIQUE

UH-1C Example Configurations

The following UH-1C armor system examples are presented to further illustrate the potential of using a computer-directed drawing instrument as a tool for designing and/or evaluating aircrew armor systems. In developing the examples, the following assumptions were made:

a. The examples drafted would include the current UH-1C aircrew armor seat.

b. Only the pilot would be considered.

c. Since the pilot's arms and legs have a low priority for protection, these body parts would not be considered.

d. The total allotted weight for armor addition is assumed to be 150 lbs.

e. Since vulnerability Parameter 1 (hit probability) indicated equal hit distribution, an appropriate set of views were chosen at random.

Two armor configurations were developed for the examples:

a. Configuration 1 -- Aircraft armor/seat armor.

b. Configuration 2 -- Aircraft armor/seat armor/body armor.

In Configuration 1, aircraft armor was used in conjunction with the current UH-1C armored seat until the 150-pound armor weight limit was reached. This configuration protects the pilot's head, torso and abdomen for a series of three directions:

Directions Covered	Figures 31 a Plan	31 b Side	32 a Plan	32 b Side	33 a Plan	33 b Side	34 a Plan	34 b Side
AZ.	0°		22°		45°		3-View Armor Composite	
EL.	-45°		-45°		-45°			

The graphics for Configuration 1 contain a series of four figures with each figure including an aircraft plan-view (a) and side-view (b) drawing. The armor additions, required to protect the crewman for the specific direction, have been indicated on each pair of drawings. For this presentation an axonometric drawing of the pilot and armored seat as they would appear from the specific direction has been inserted in the upper right corner of each aircraft side-view drawing. This axonometric drawing, drafted by the computer-directed drawing instrument, visually defines the crew body parts requiring protection and effects the accurate placement of protective armor on the aircraft drawings. The last figure in the series presents a three-view armor composite which illustrates the protection overlap that occurs during the armor development activity.

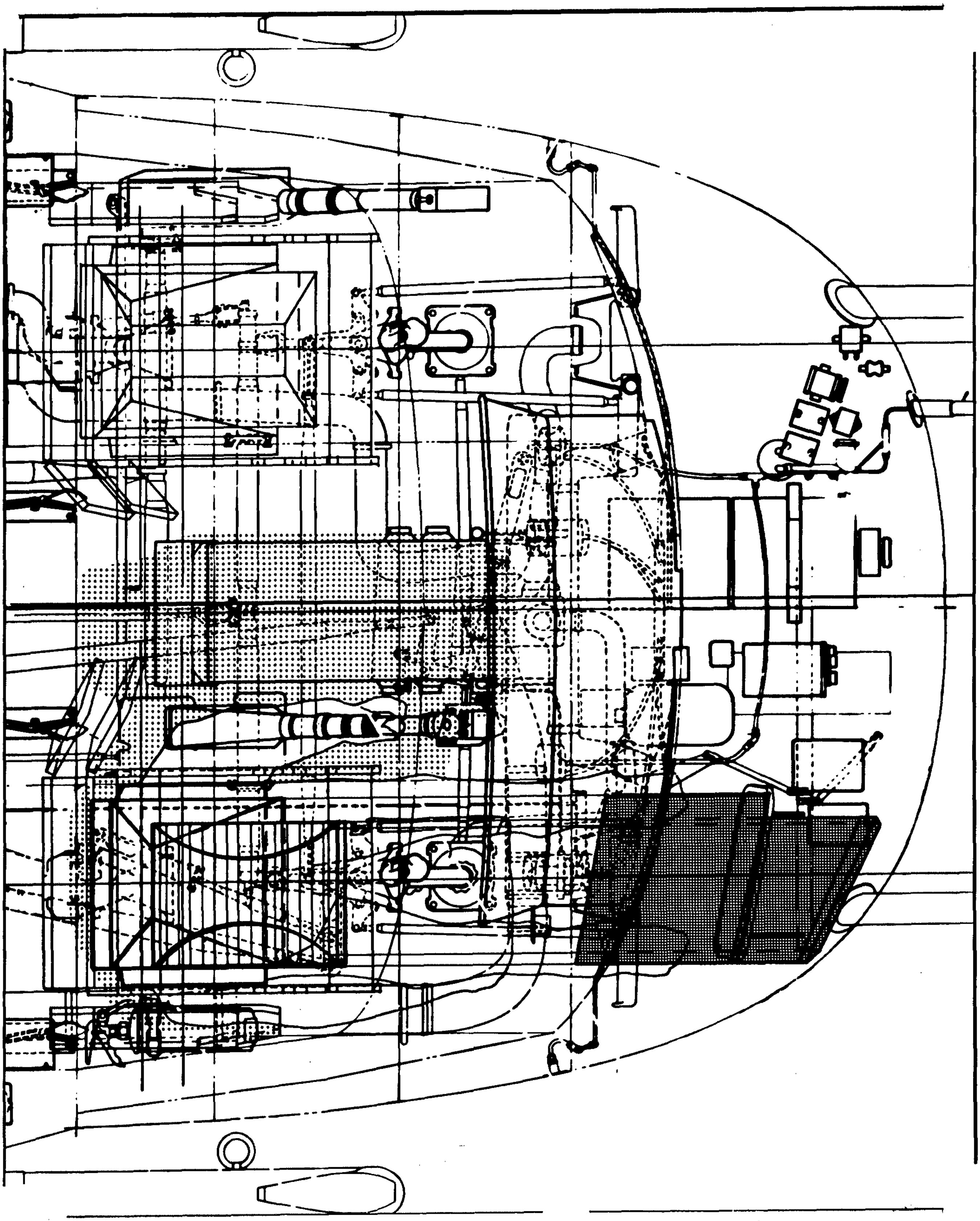

Fig. 31a. ARMOR CONFIGURATION 1 -- PLAN VIEW   0° AZIMUTH, -45° ELEVATION

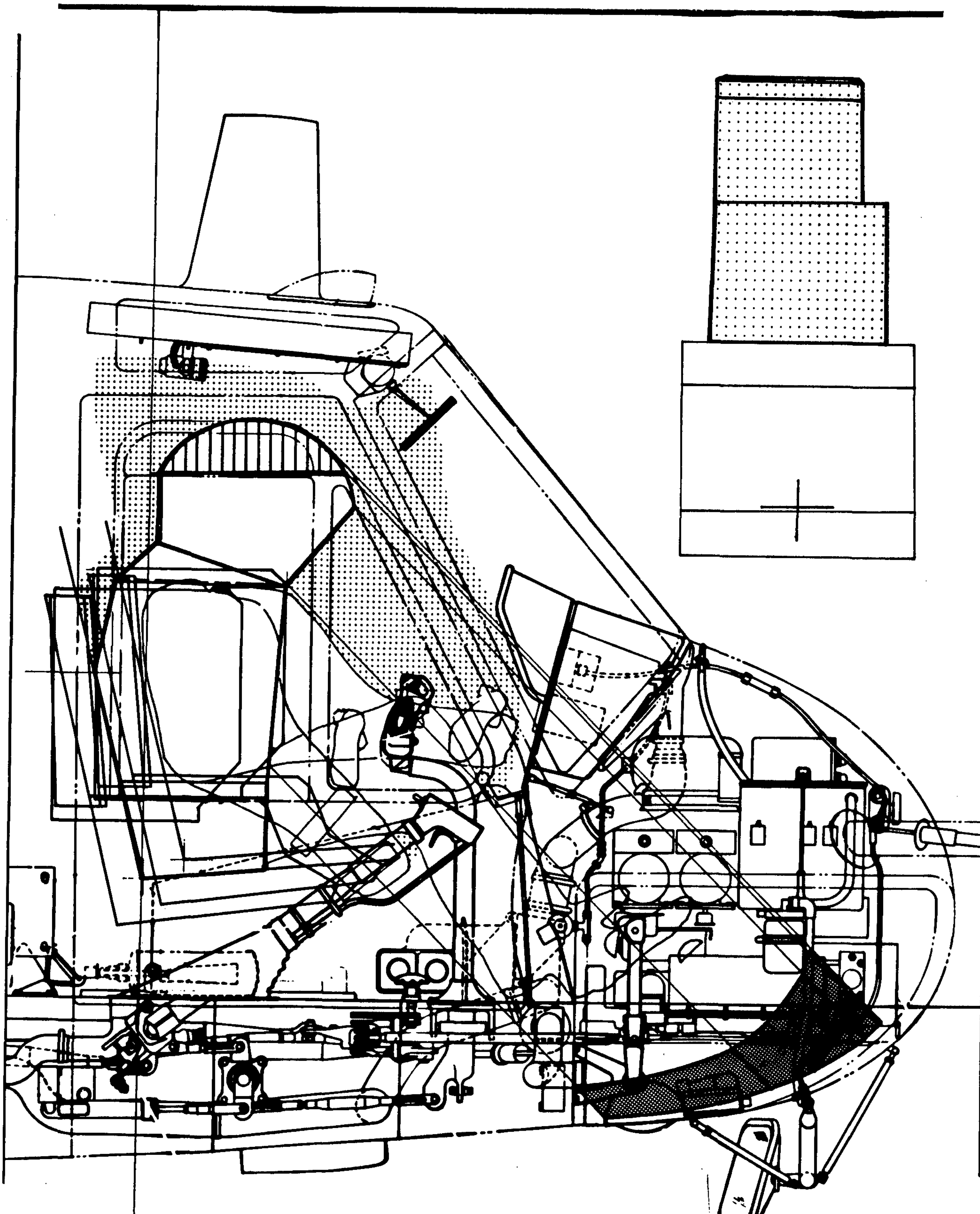

Fig. 31b. ARMOR CONFIGURATION 1 -- SIDE VIEW 0^o AZIMUTH, -45^o ELEVATION

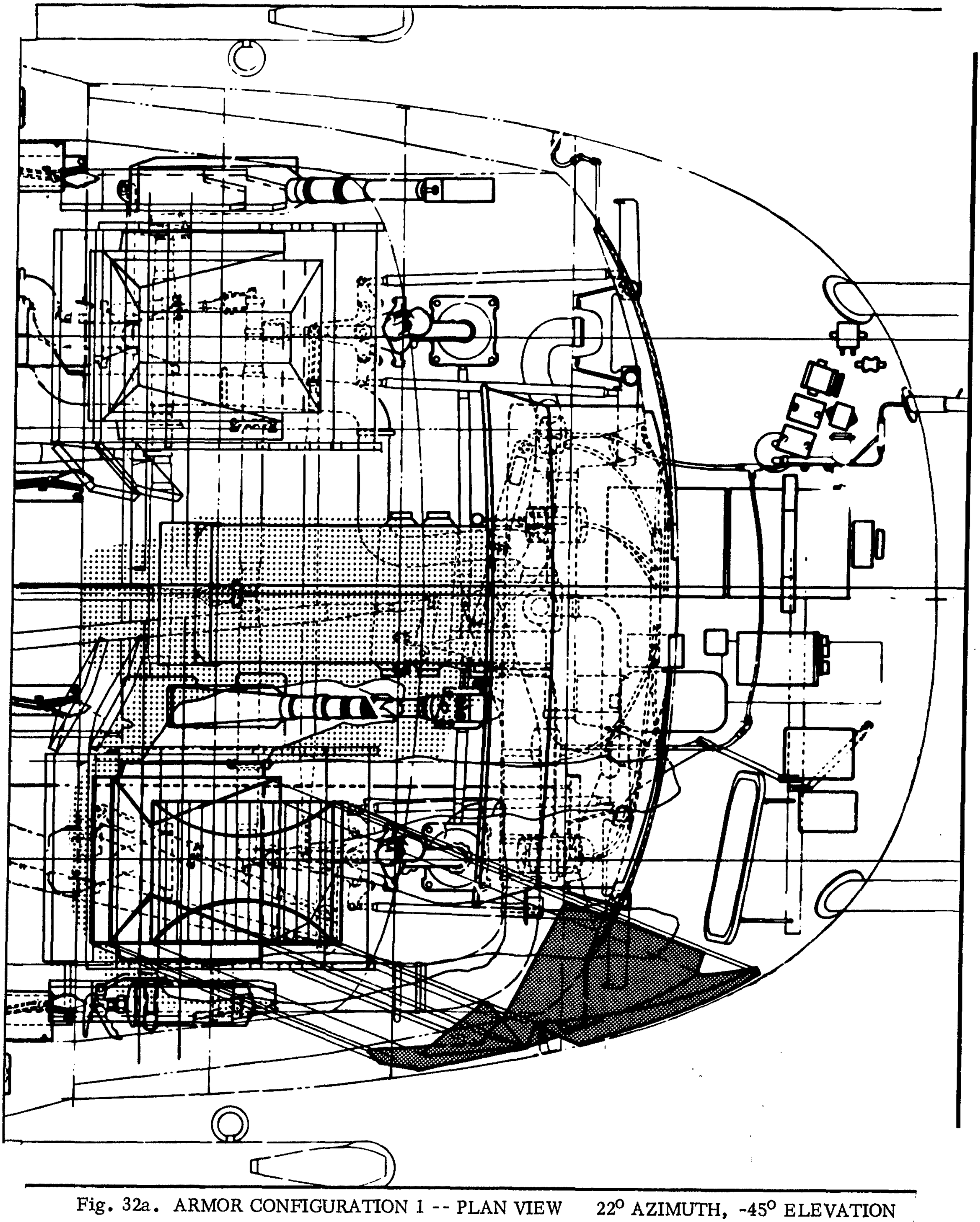

Fig. 32a. ARMOR CONFIGURATION 1 -- PLAN VIEW 22° AZIMUTH, -45° ELEVATION

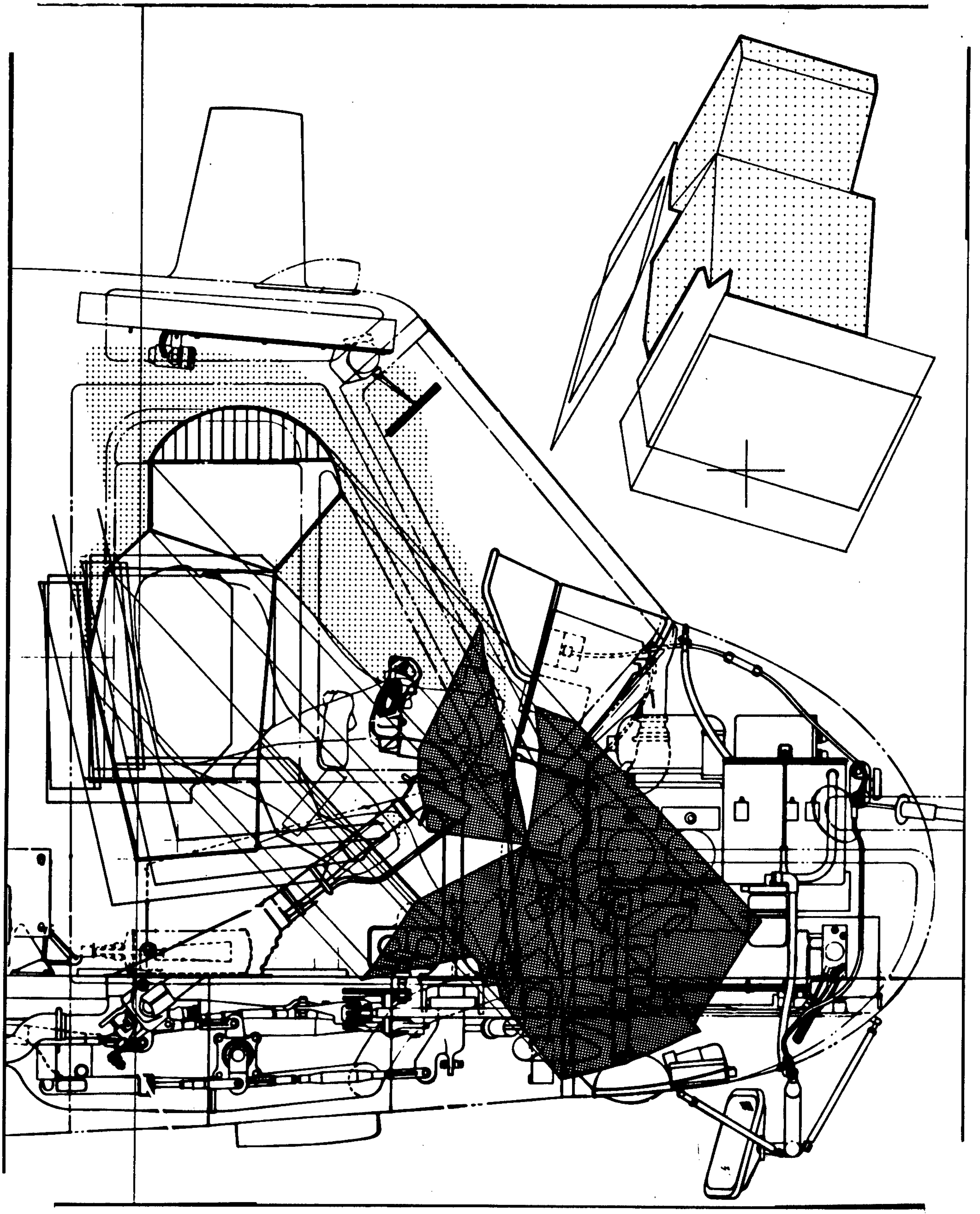

Fig. 32b. ARMOR CONFIGURATION 1 -- SIDE VIEW 22° AZIMUTH, -45° ELEVATION

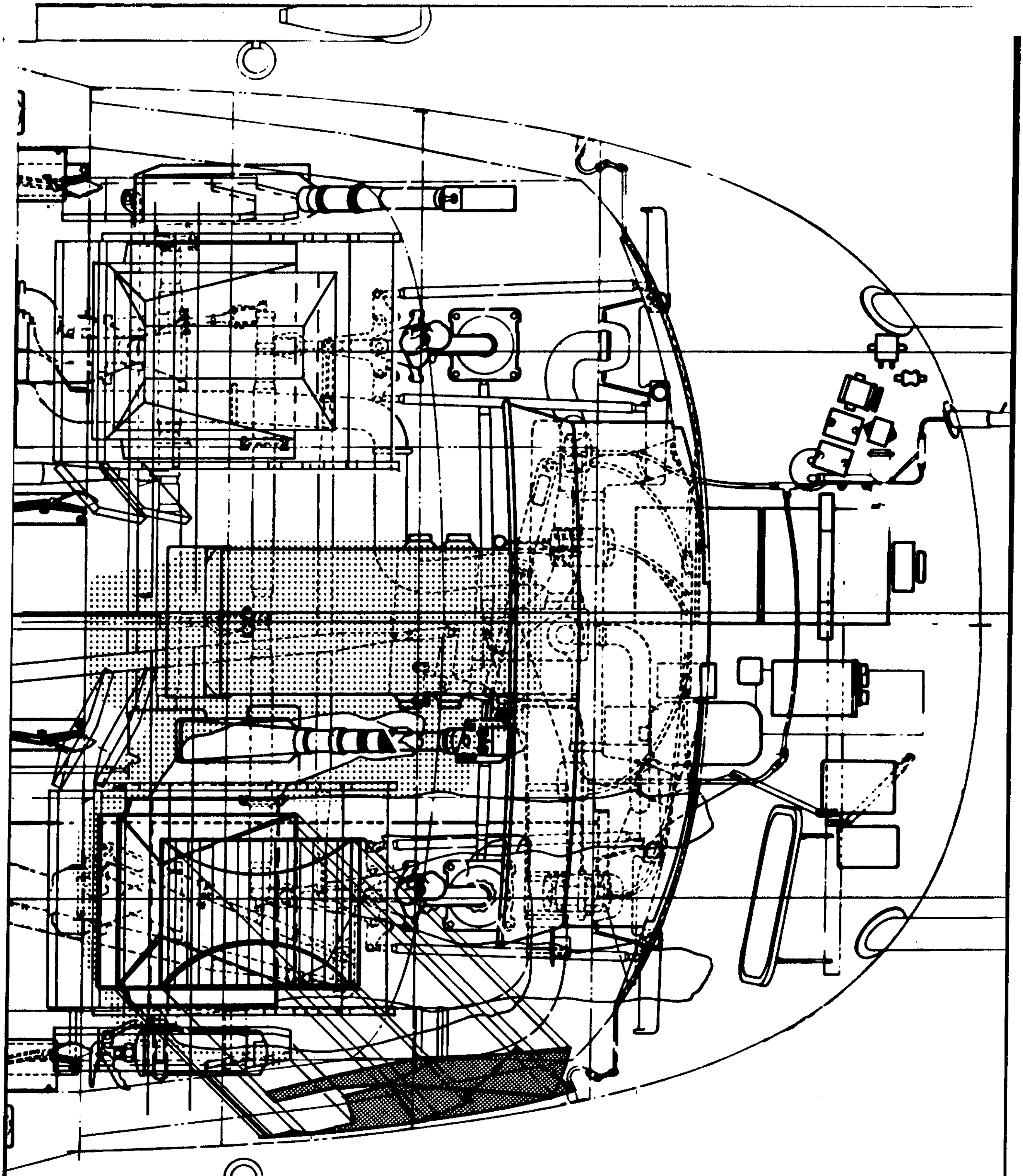

Fig. 33a. ARMOR CONFIGURATION 1 -- PLAN VIEW 45° AZIMUTH, -45° ELEVATION

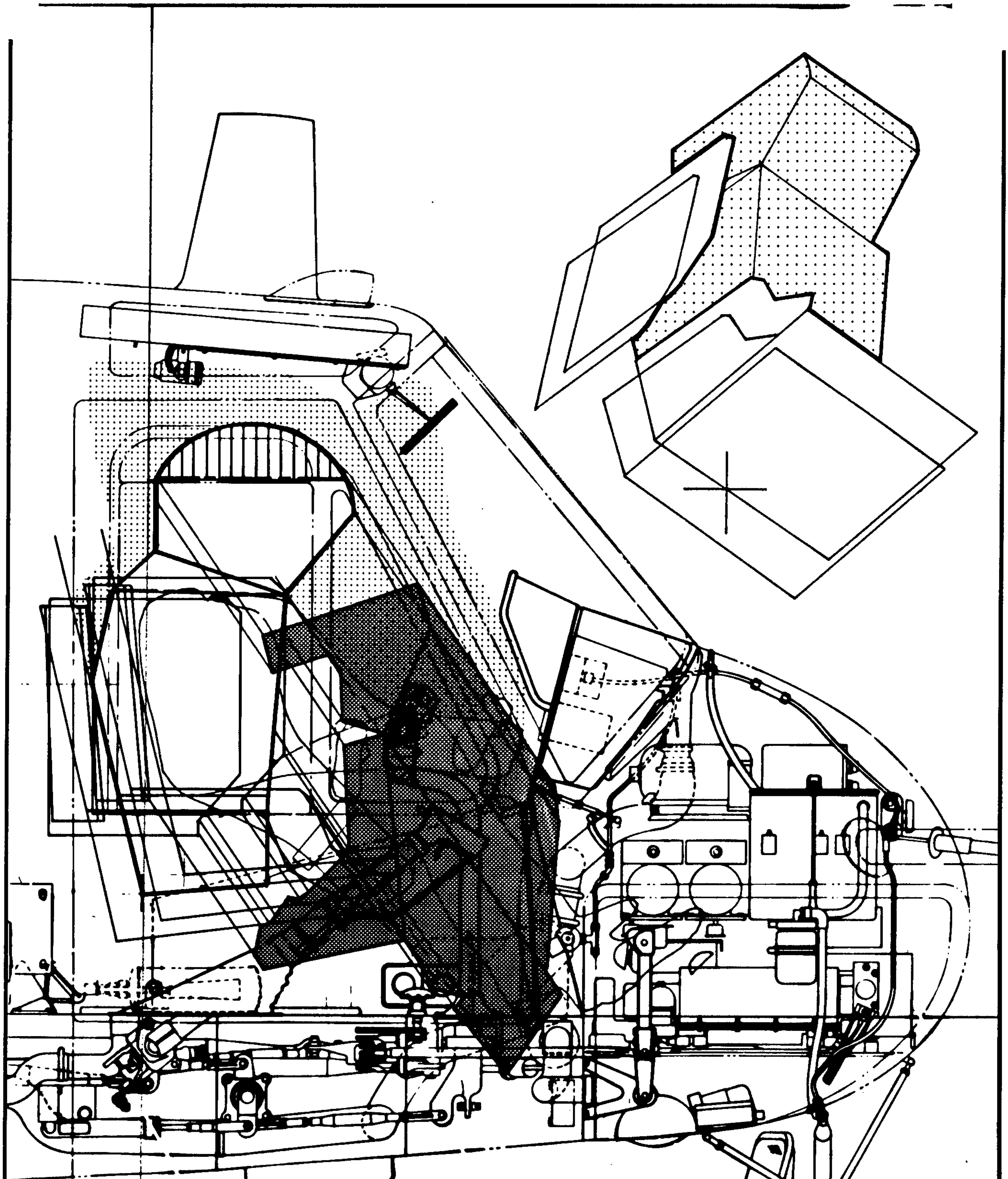

Fig. 33b. ARMOR CONFIGURATION 1 -- SIDE VIEW 45° AZIMUTH, -45° ELEVATION

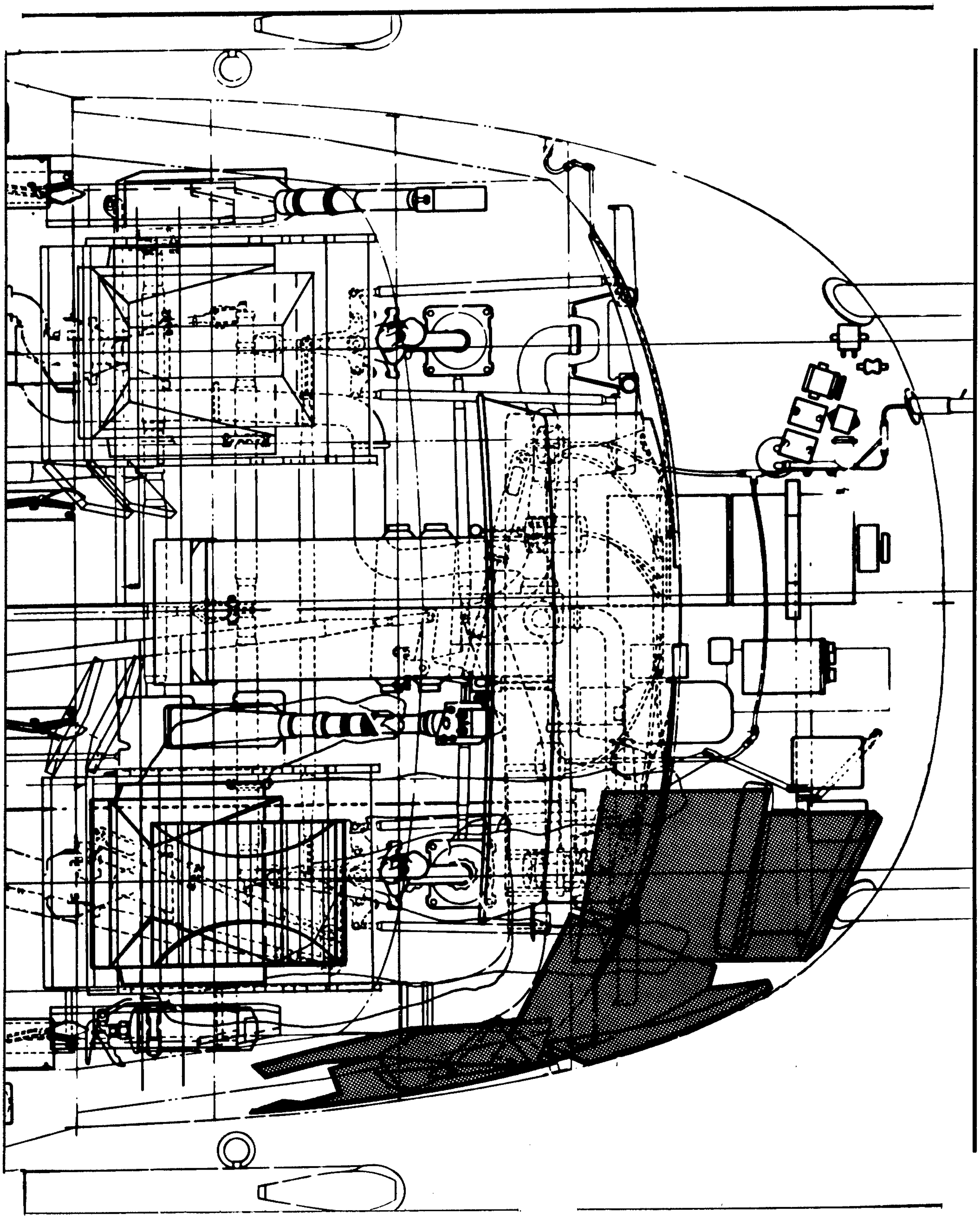

Fig. 34a. ARMOR CONFIGURATION 1 -- COMPOSITE/PLAN VIEW

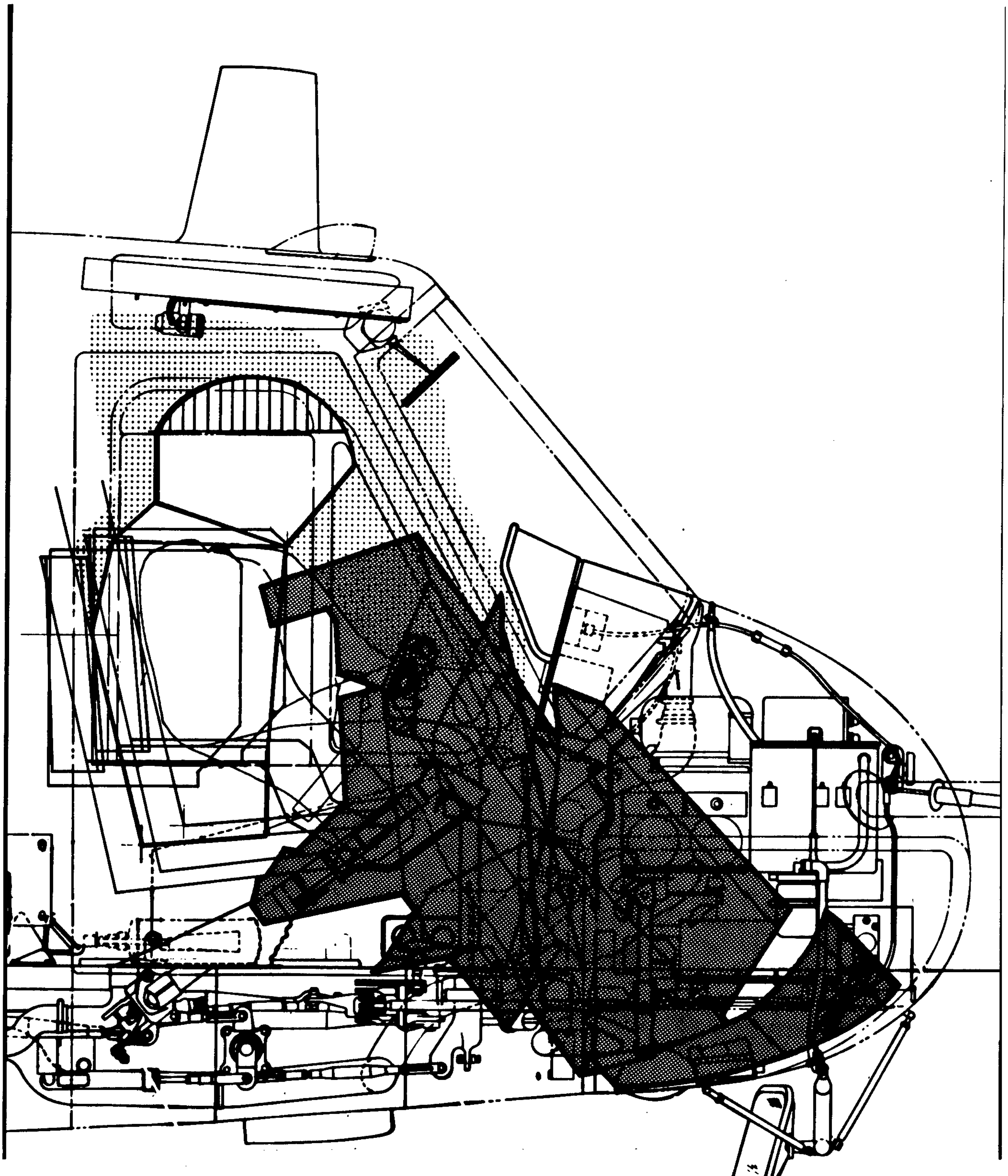

Fig. 34b. ARMOR CONFIGURATION 1 -- COMPOSITE/SIDE VIEW

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In Configuration 2, aircraft armor and body armor were used in conjunction with the current UH-1C armored seat. This configuration protects the pilot's head, torso, and abdomen for a series of five directions:

Directions Covered	Figures 35		36		37		38		39		40	
	a Plan	b Side	a Plan	b Side	a Plan	b Side	a Plan	b Side	a Plan	b Side	a Plan	b Side
AZ.	0°		22°		45°		67.5°		90°		5-View Armor Composite	
EL.	-45°		-45°		-45°		-45°		-45°			

As in Configuration 1, each of the six figures in this second series contains an aircraft plan-view (a) and side-view (b) drawing with the required armor additions indicated. Utilizing body armor to protect the pilot's torso allowed two additional directions to be covered before the armor weight limit was reached. The axonometric drawings included on the aircraft side views define the pilot's body parts requiring protection and indicate that the torso armor in this configuration would have more wrap-around than current torso armor systems. The last figure in this series presents the five-view armor composite which illustrates the overlap that occurs as the configuration is developed.

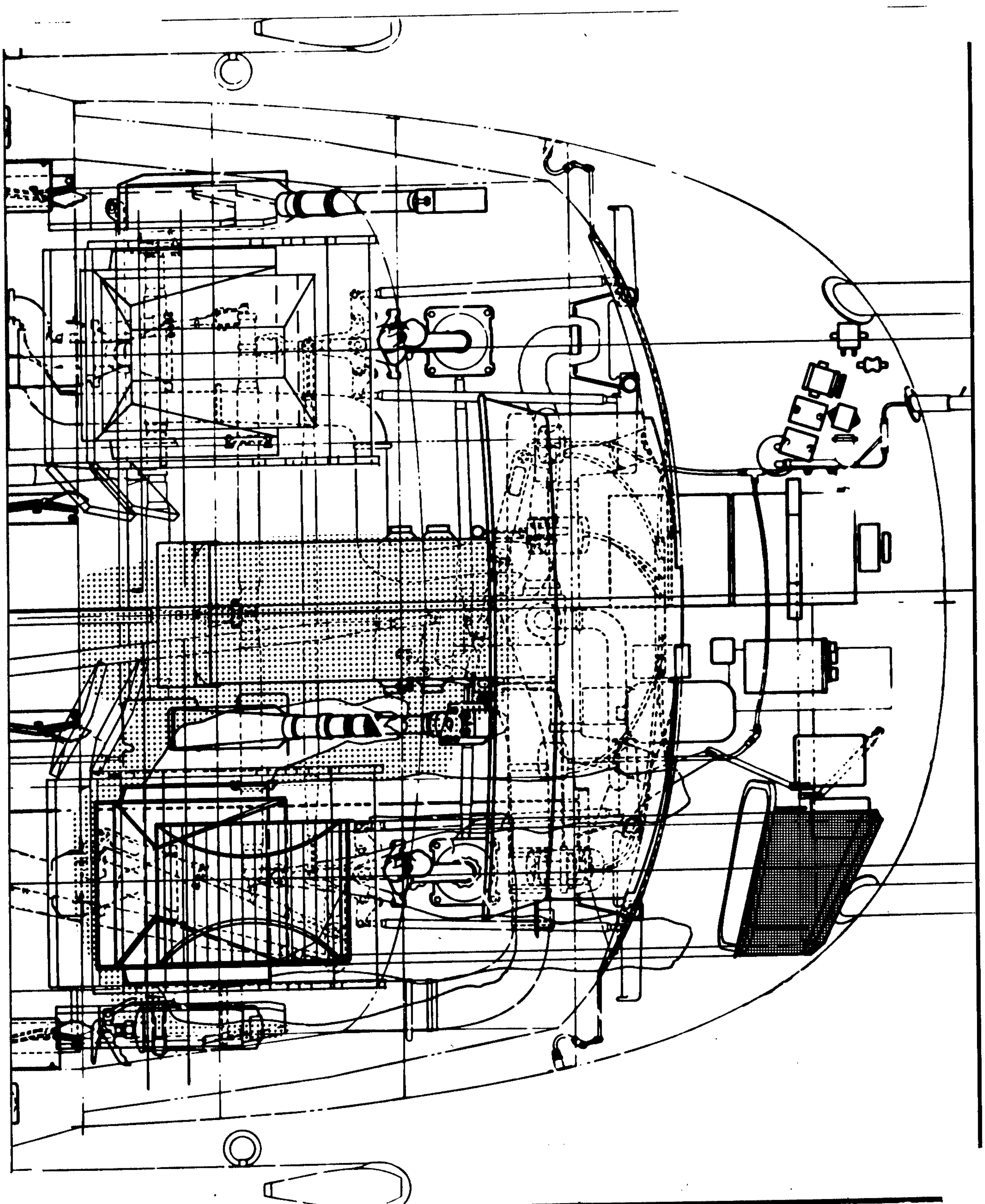

Fig. 35a. ARMOR CONFIGURATION 2 -- PLAN VIEW 0° AZIMUTH, -45° ELEVATION

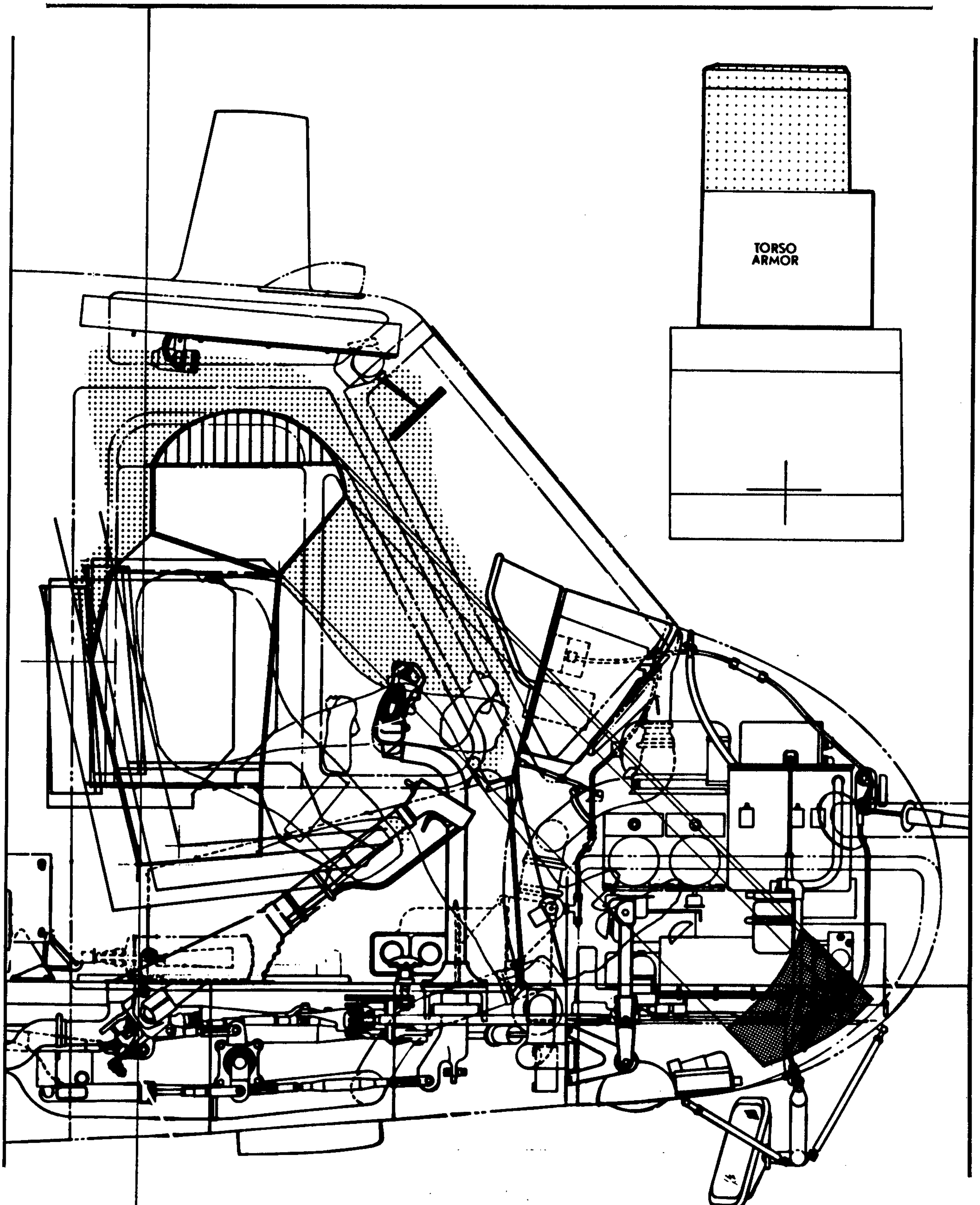

Fig. 35b. ARMOR CONFIGURATION 2 -- SIDE VIEW 0° AZIMUTH, -45° ELEVATION

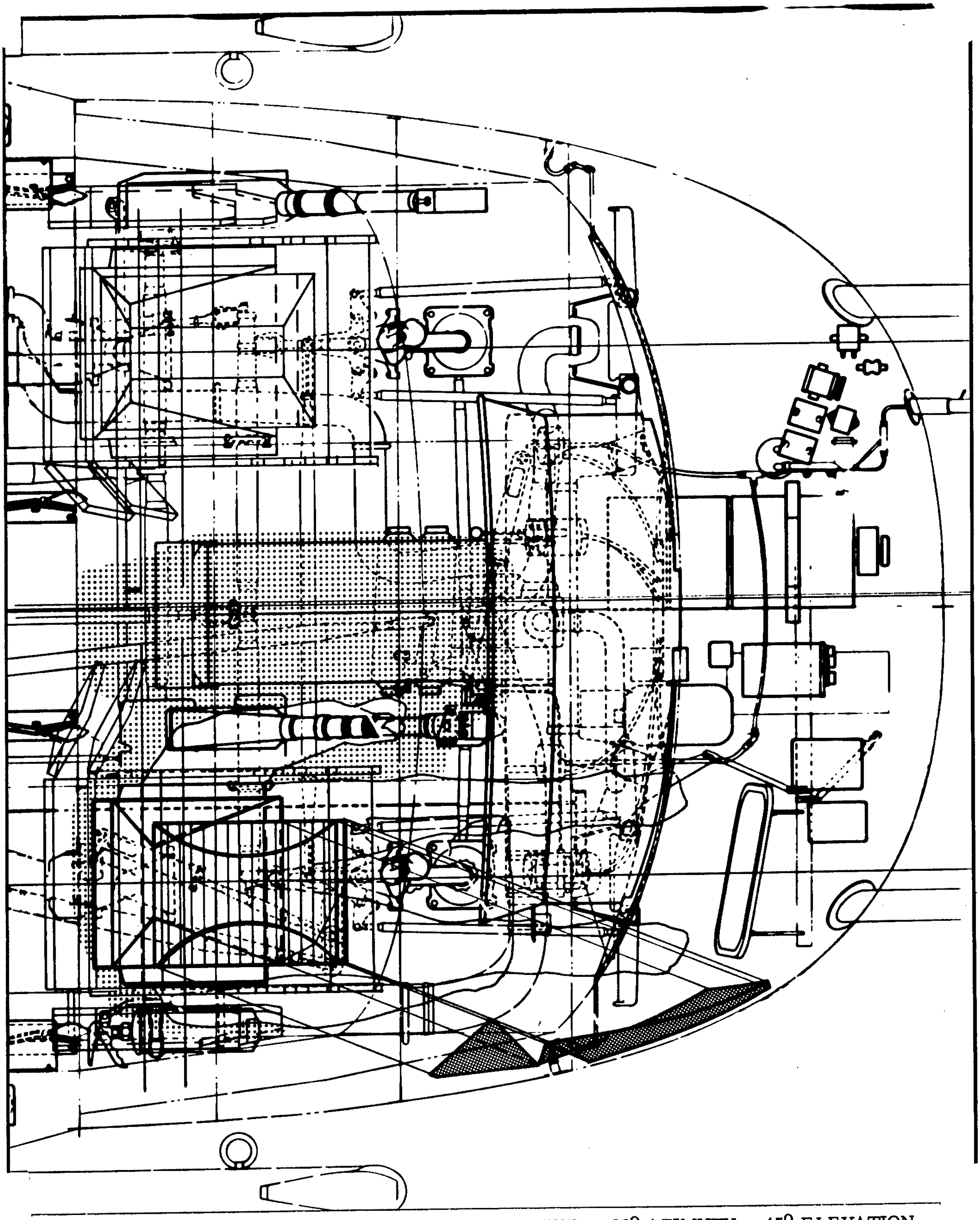

Fig. 36a. ARMOR CONFIGURATION 2 -- PLAN VIEW 22° AZIMUTH, -45° ELEVATION

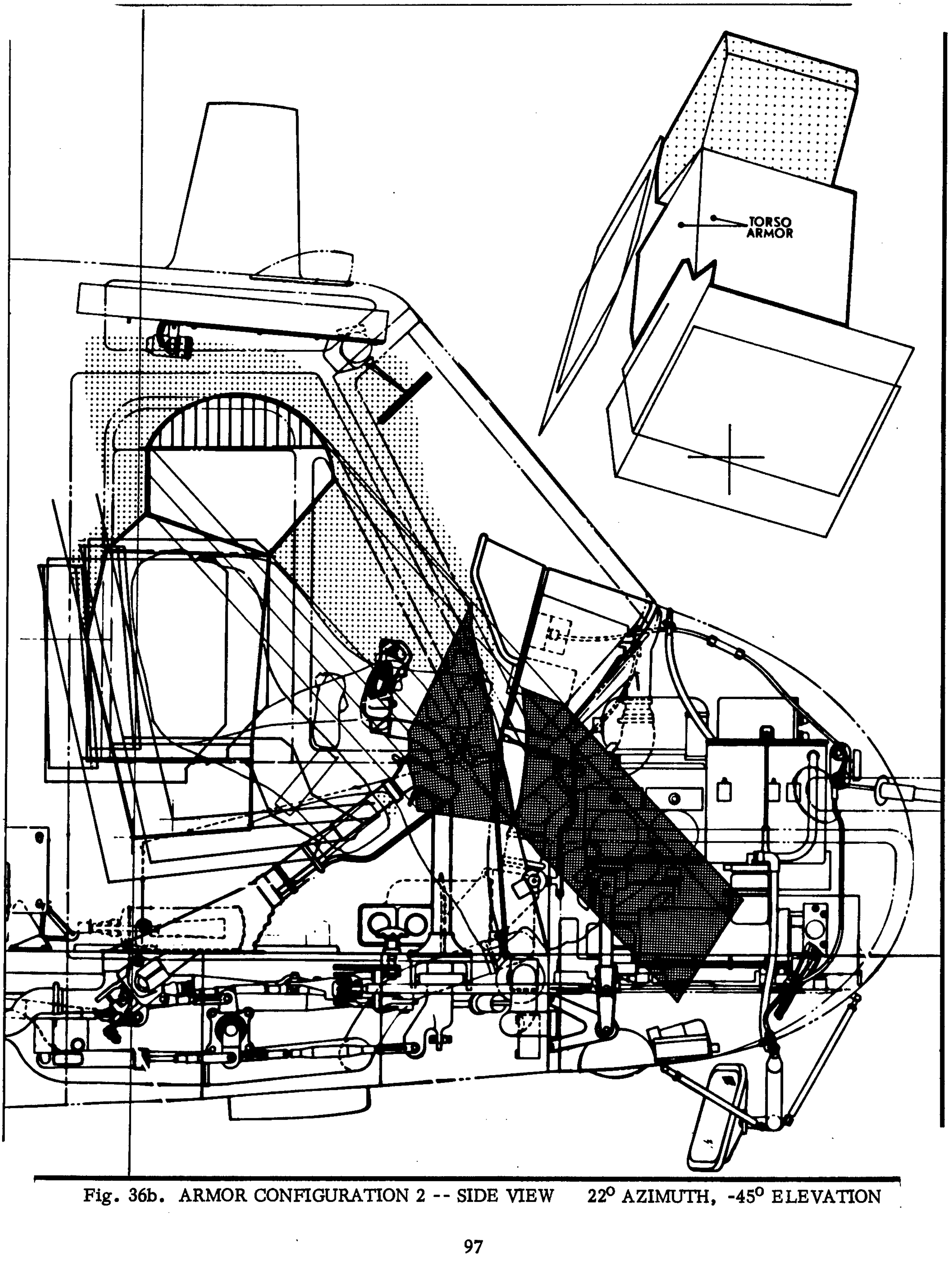

Fig. 36b. ARMOR CONFIGURATION 2 -- SIDE VIEW 22° AZIMUTH, -45° ELEVATION

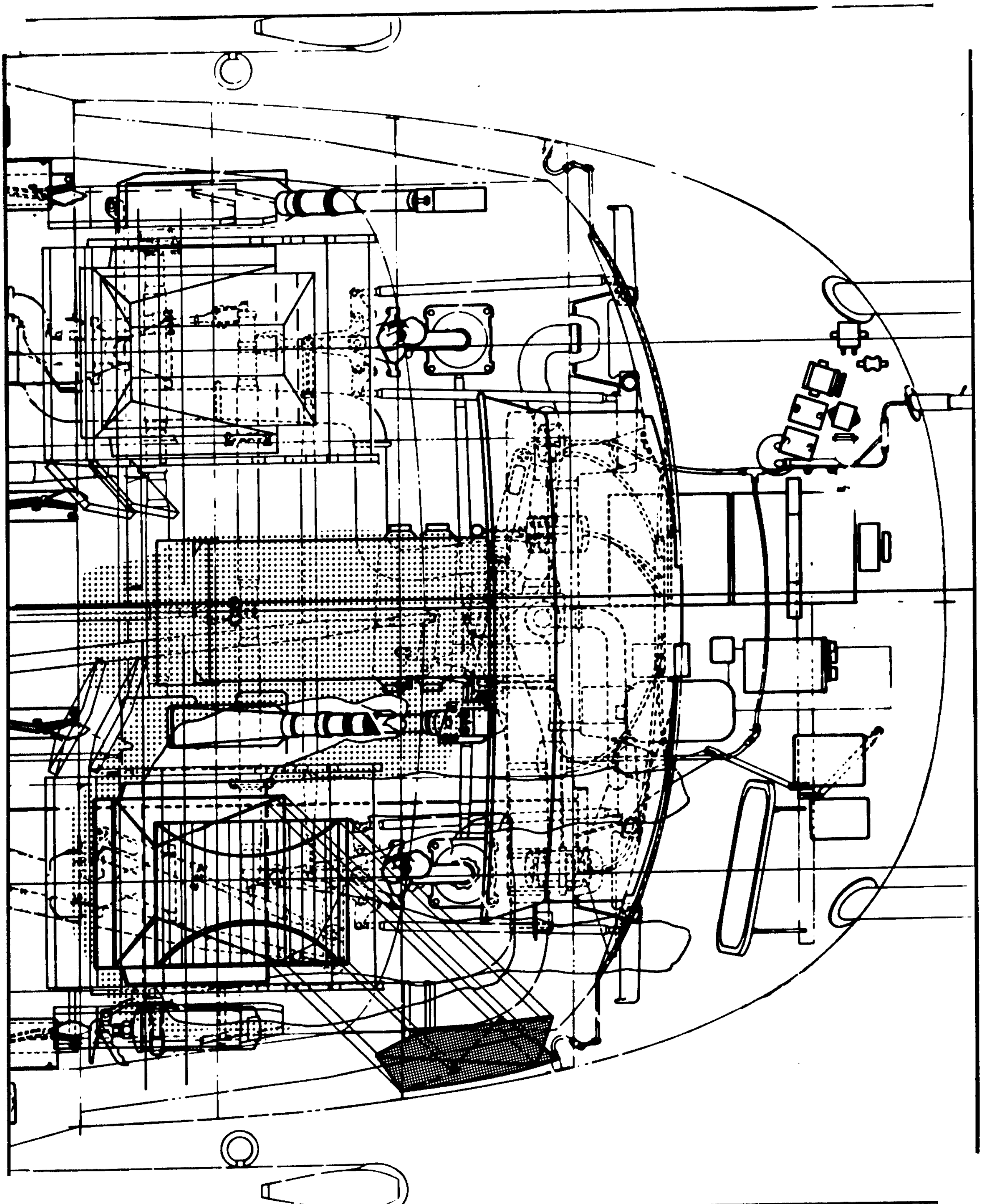

Fig. 37a. ARMOR CONFIGURATION 2 -- PLAN VIEW 45° AZIMUTH, -45° ELEVATION

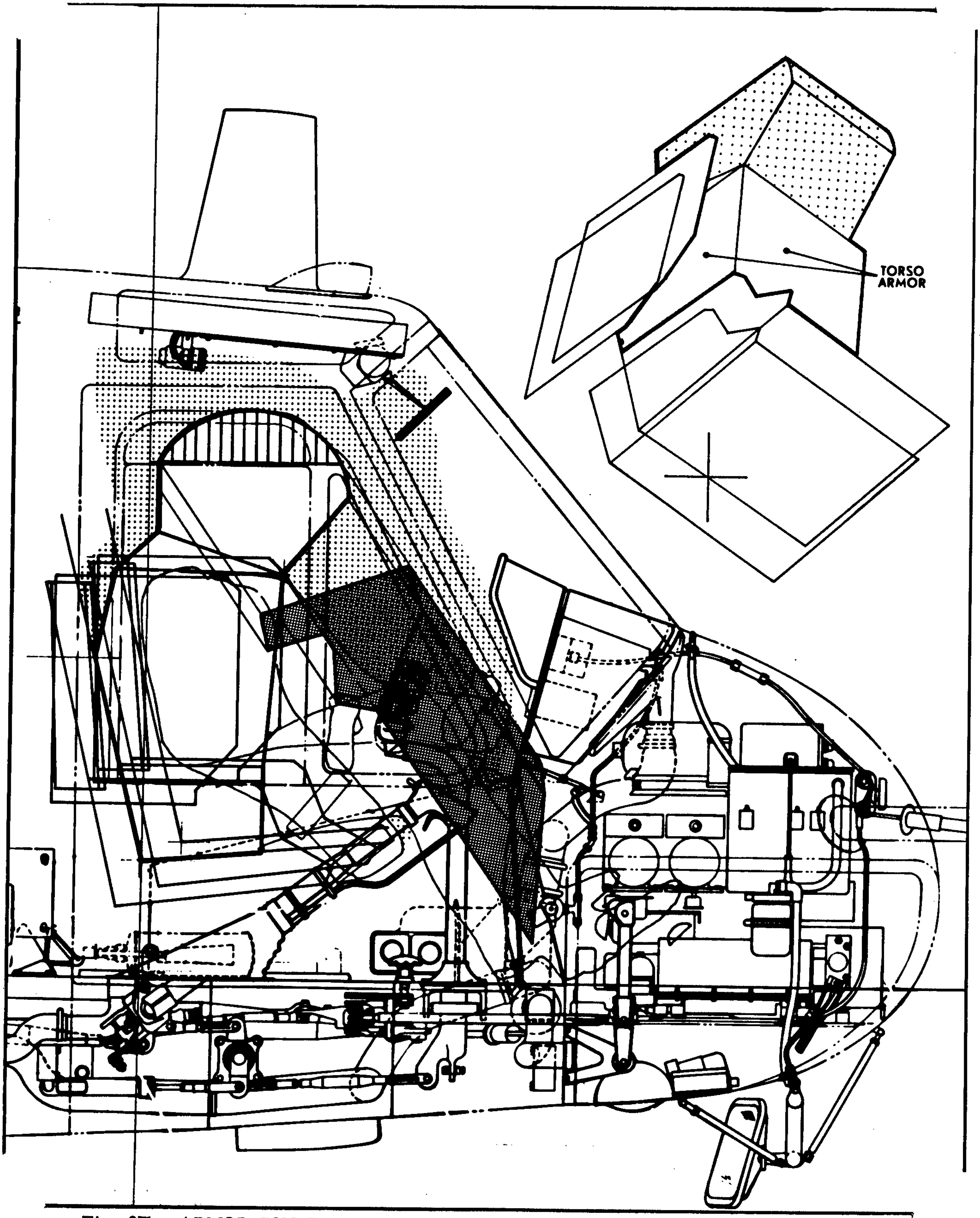

Fig. 37b. ARMOR CONFIGURATION 2 -- SIDE VIEW 45° AZIMUTH, -45° ELEVATION

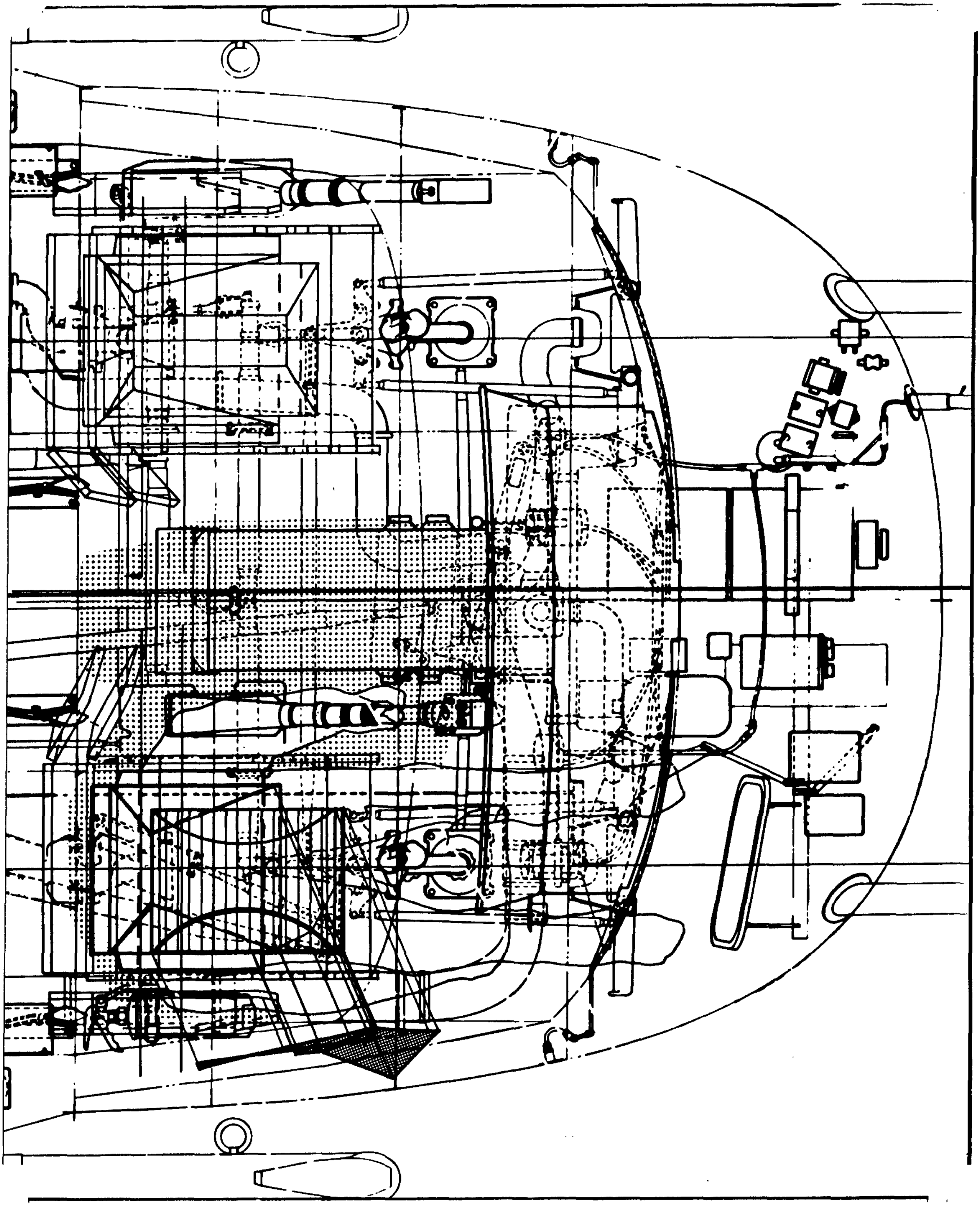

Fig. 38a. ARMOR CONFIGURATION 2 -- PLAN VIEW 67.5° AZIMUTH, -45° ELEVATION

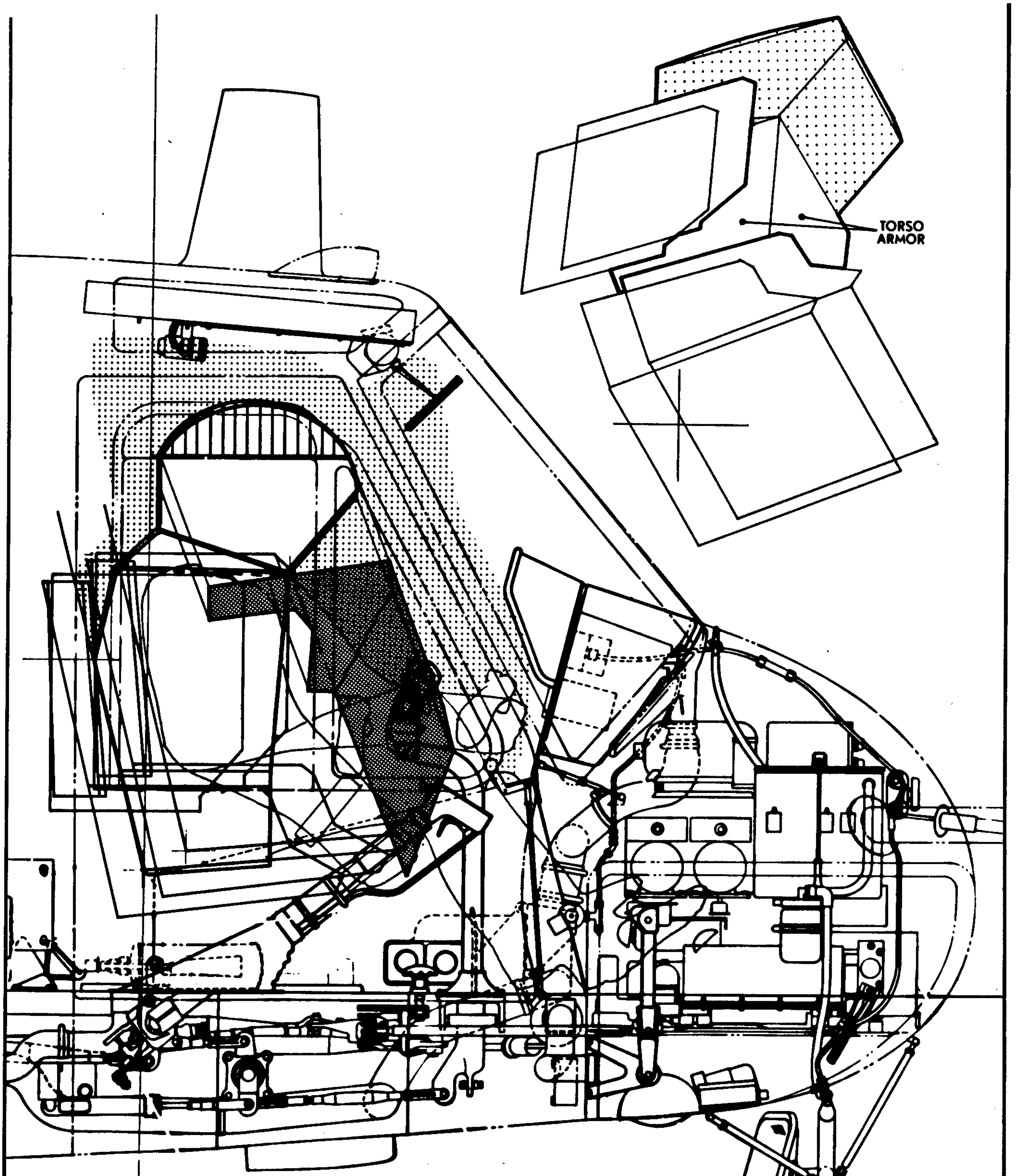

Fig. 38b. ARMOR CONFIGURATION 2 -- SIDE VIEW 67.5° AZIMUTH, -45° ELEVATION

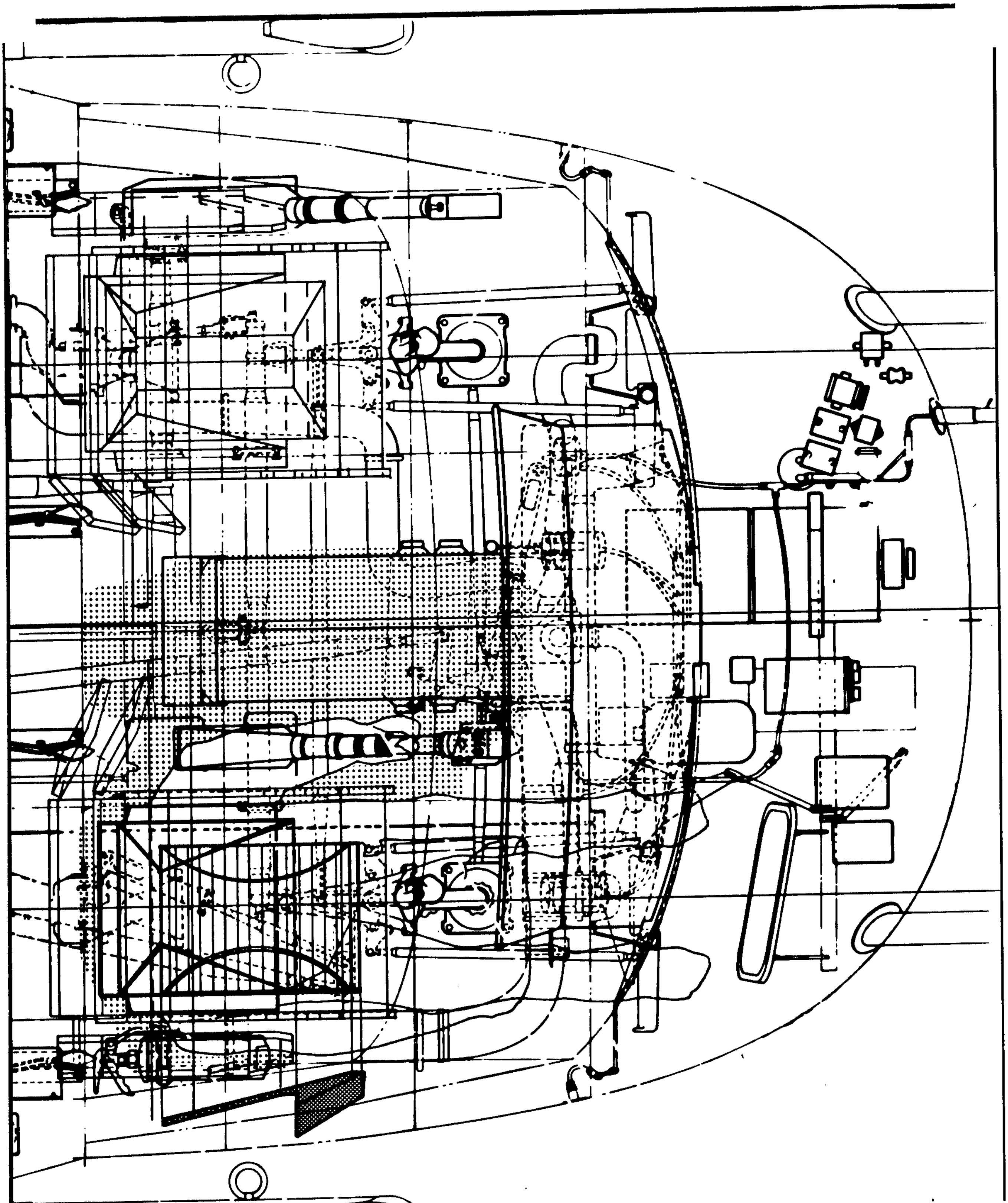

Fig. 39a. ARMOR CONFIGURATION 2 -- PLAN VIEW 90° AZIMUTH, -45° ELEVATION

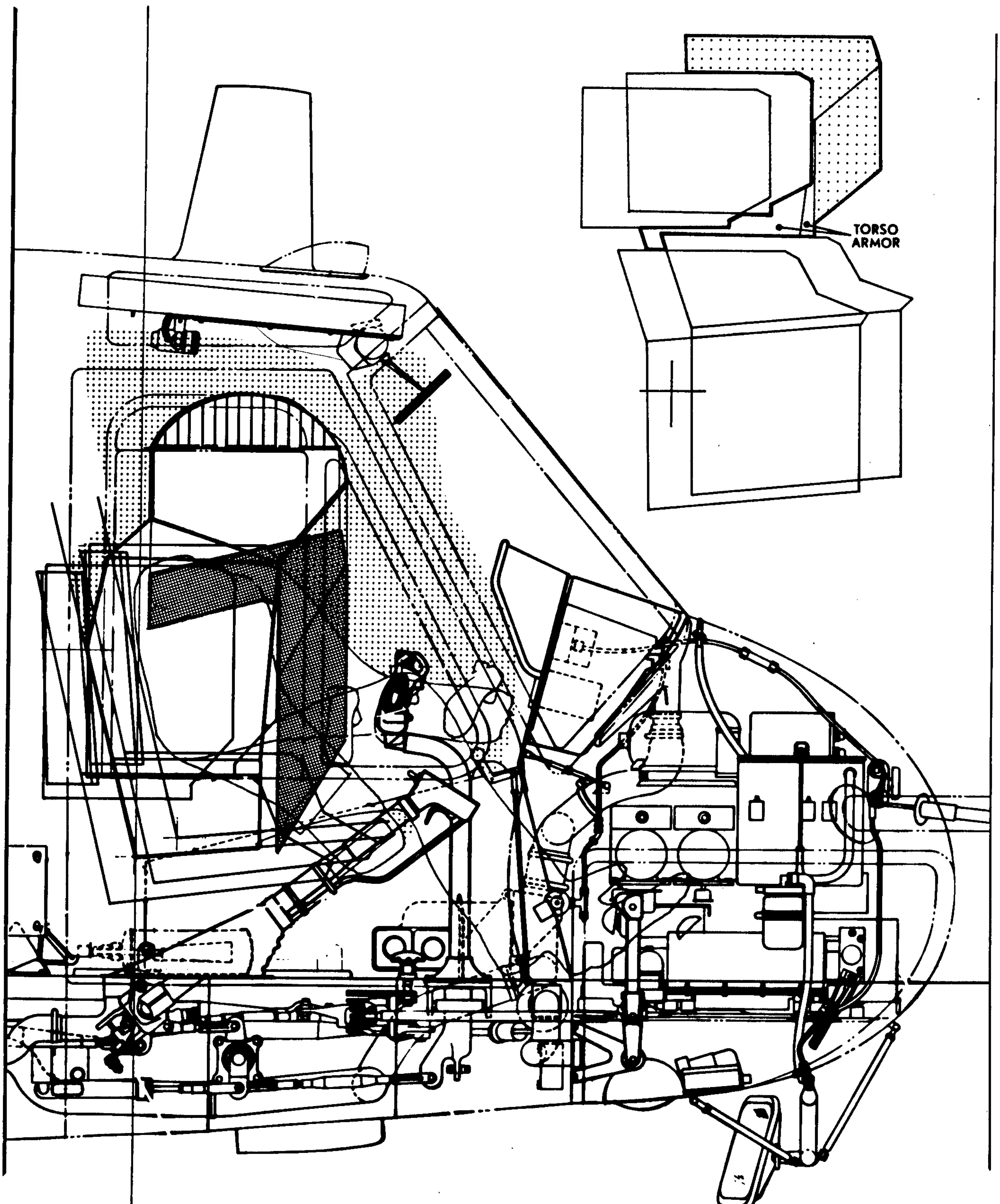

Fig. 39b. ARMOR CONFIGURATION 2 -- SIDE VIEW 90° AZIMUTH, -45° ELEVATION

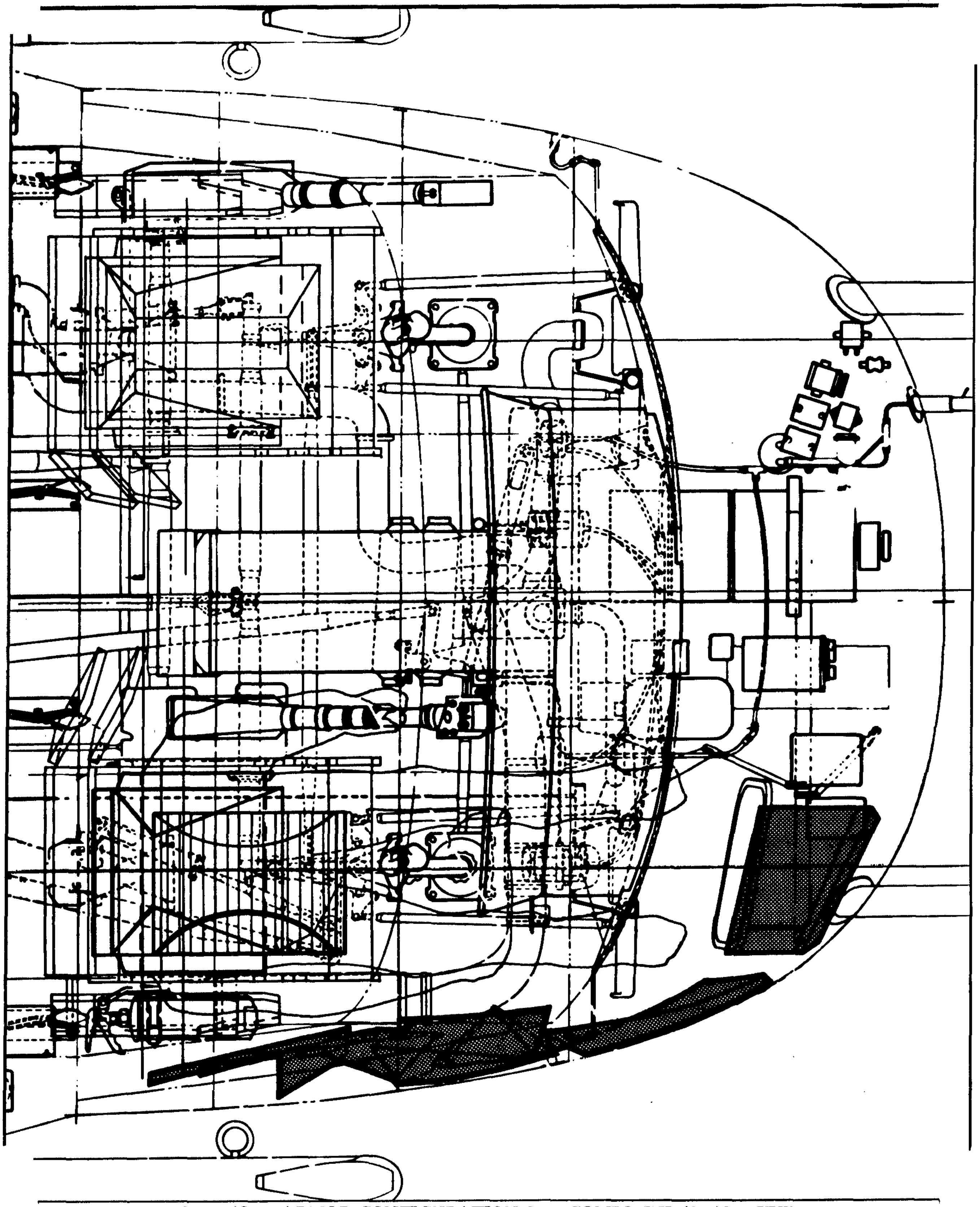

Fig. 40a. ARMOR CONFIGURATION 2 -- COMPOSITE/PLAN VIEW

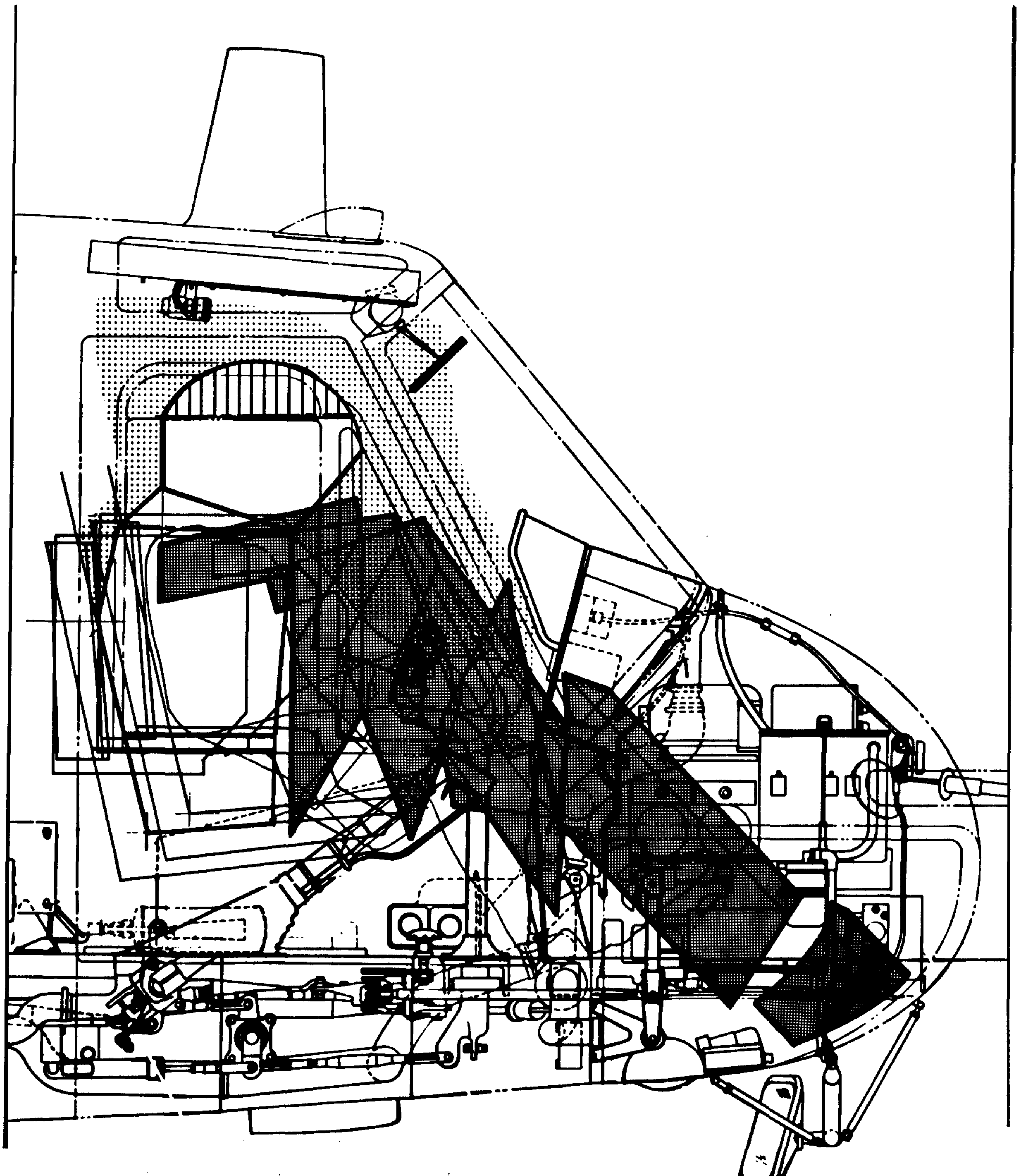

Fig. 40b. ARMOR CONFIGURATION 2 -- COMPOSITE/SIDE VIEW

Discussion

With the various armor configurations developed, they must be analyzed to insure that the following conditions are satisfied:

a. Armor weight (W_A) + necessary ballast weight (W_B) = total additional weight that the aircraft can tolerate.

b. The moment change (center of gravity shift) related to the weight additions (armor/ballast) is within the system's acceptable CG shift limits.

For existing aircraft, these weight and CG limits are established by methods similar to those outlined in Phase I of this guideline. For proposed aircraft, these limits are specified in the early weight and balance studies.

Summary

Using the methods and procedures outlined in this section, several armor configurations can be developed which will provide the crew with varying degrees of armor protection. Once the development phase is completed, however, the configurations must be evaluated in terms of degrees of protection, crew task interference, and aircraft performance decrement. Although a particular system may offer greater protection, it may also cause excessive flight-control interference, impair crew vision or hamper emergency egress procedures. An effectiveness evaluation will reveal any problem areas in a proposed system and would indicate what measures should be taken to optimize the configuration; i.e., armor configuration changes, relocation of aircraft components, changes in crew-station layout criteria, etc.

SECTION II. ARMOR SYSTEMS EFFECTIVENESS EVALUATION

Once the configurations of armor have been established to approach some degree of the crew "protection need," the effects of each configuration on the crew/aircraft performance can be evaluated using the following system parameters:

For each armor configuration define:

1. ΔCP_K = The change in aircrew protection.
2. ΔW_K = The change in the aircraft systems weight.
3. ΔV_K = The change in the crew's field of vision from the vision standard (MIL-STD-850A).
4. ΔME_K = The change in the crew's motion envelope.

where $\Delta(\ )_K$ refers to the changes brought about by the armor configurations being developed.

Additional system parameters may be added at the discretion of the investigator. The only limit is the feasibility of obtaining measures on the additional parameters.

Computational Methods

Of the armor systems being evaluated, that system is optimal which produces the <u>largest</u> positive change in system Parameter 1 and the <u>smallest</u> negative change in system Parameters 2 through 4.

The smallest negative change in system Parameters 2 through 4 above can be expressed using the following equation:

$$P \Delta W_K + Q \Delta V_K + R \Delta ME_K + \ldots = Total_K$$

where P, Q, R, ..., are weighting factors such that:

$$P + Q R + \ldots = 1.$$

These weighting factors would be determined by the predominant mission requirements of the vehicle under consideration, i.e., payload capacity, aircraft/aircrew performance requirements, protection requirements, and cost effectiveness studies.

a. Change in crew protection (ΔCP_K).

Computing the change in crew protection brought about by the proposed armor configuration is based on the four vulnerability parameters formulated in Phase II of the guideline:

P(h) - Probability distribution of projectile hits on the aircraft by direction.

P(p) - Probability of a projectile from a particular direction penetrating a particular section of the crew motion envelope.

P(i) - Probability of hitting a particular body part i in a particular section of the crew motion envelope.

P(k) - Probability of kill given a hit on a particular body part i.

The product of these four vulnerability parameters will produce a number "n" or "protection need" number for each crewman's body-part/direction combination according to the following formula:

$$n = P(h\ p\ i\ k) = P(h)\, P(p)\, P(i)\, P(k)$$

The "protection need" numbers are listed in the "protection need" matrix which indicates the body-part/direction combinations having the highest protection need. When developing an armor configuration, only those body parts having the highest "n" or "protection need" numbers would be considered in the design study. The change in crew protection is established using the formula:

$$(\Delta CP_K) = n_1 + n_2 + n_3 + \ldots = N_T$$

where N_T denotes the sum total of the crewman's "protection need" numbers covered by the proposed armor system.

Examples:

Computations of the UH-1 pilot's change in protection (ΔCP_K) reflected in the sample armor configurations are presented in Tables 12 and 13.

TABLE 12

Change in Protection Index for Configuration 1
(Aircraft Armor/Seat Armor)

Direction of Fire Protected		Body-Part Numbers Protected						
Azimuth	Elevation	1	2	3	4	5	6	7
0.0	-45	38.4	40.5	00				
22.5	-45	38.4	40.5	00				
45.0	-45	38.4	40.5	00				

$(\Delta CP_K) = 38.4 + 40.4 + 38.4 + \ldots n = \text{Total}_N$

$N_T = 236.7$

TABLE 13

Change in Protection Index for Configuration 2
(Aircraft/Seat/Body Armor)

Direction of Fire Protected		Body-Part Numbers Protected						
Azimuth	Elevation	1	2	3	4	5	6	7
0.0	-45	38.4	40.5	00				
22.5	-45	38.4	40.5	00				
45.0	-45	38.4	40.5	00				
67.5	-45	38.4	40.5	00				
90.0	-45	38.4	40.5	00				

$(\Delta CP_K) = 38.4 + 40.5 + \ldots n = \text{Total}_N$

$N_T = 394.5$

b. Change in the aircraft systems weight (ΔW_K)

In any aircraft there is a limit to the amount of armor weight that can be added to the system. The change in the aircraft systems weight (ΔW_K) is then expressed as the percent of the armor weight allotment that is used by the proposed armor configuration.

Example:

For our study, it was assumed that a maximum of 150 lbs. of additional weight would be allotted to the protection of the UH-1 pilot. The change in the aircraft system weight, related to each configuration, was established as follows:

Configuration 1. The armor composite (Fig. 34) indicates that Configuration 1 has a total area of approximately 7.5 sq. ft. Assuming that the armor and supporting material weigh 20 lbs. per sq. ft., Configuration 1's computed weight is approximately 150 lbs.:

$$W_K = \frac{\text{150 lbs. configuration weight}}{\text{150 lbs. weight allotment}} = 1.$$

Configuration 2. The armor composite (Fig. 40) indicates that Configuration 2, including the pilot's torso armor, has a total area of approximately 5.5 sq. ft., weighing approximately 110 lbs:

$$W_K = \frac{\text{110 lbs. configuration weight}}{\text{150 lbs. weight allotment}} = .73$$

Fig. 41a. BINOCULAR COCKPIT VISIBILITY PHOTOGRAPH - UH-1 AIRCRAFT

c. Change in field of vision from the standard (ΔV_K)

Using MIL-STD-850A, Aircrew Standard Vision Requirements for Military Aircraft (Department of Defense, 1967), any change from the standard can be established on the aircraft engineering drawings or on the standard vision plot for the aircraft system. A binocular cockpit visibility photograph (Fig. 41a) can be superimposed over the aircraft's standard vision plot to achieve a greater appreciation of the proposed armor/vision overlap. The change in field of vision from the standard is then expressed as the percent or decimal part of the vision standard that is obstructed by the armor system under consideration.

Example:

Computation of the change in vision (ΔV_K) brought about by the study configurations is presented in the following vision plots:

Configuration 1 (Fig. 41b). The UH-1 vision standard was divided into units representing 5^o azimuth (left/right) and 5^o elevation (up/down), with the standard containing a total of 510 units. Configuration 1 overlaps a total of 4.5 units of the standard.

$$\frac{4.5}{510} = 0.0088 \text{ units overlap.}$$

Configuration 2 (Fig. 42). Configuration 2 overlaps the vision standard a total of 3.0 units.

$$\frac{3.0}{510} = 0.0058 \text{ units overlap.}$$

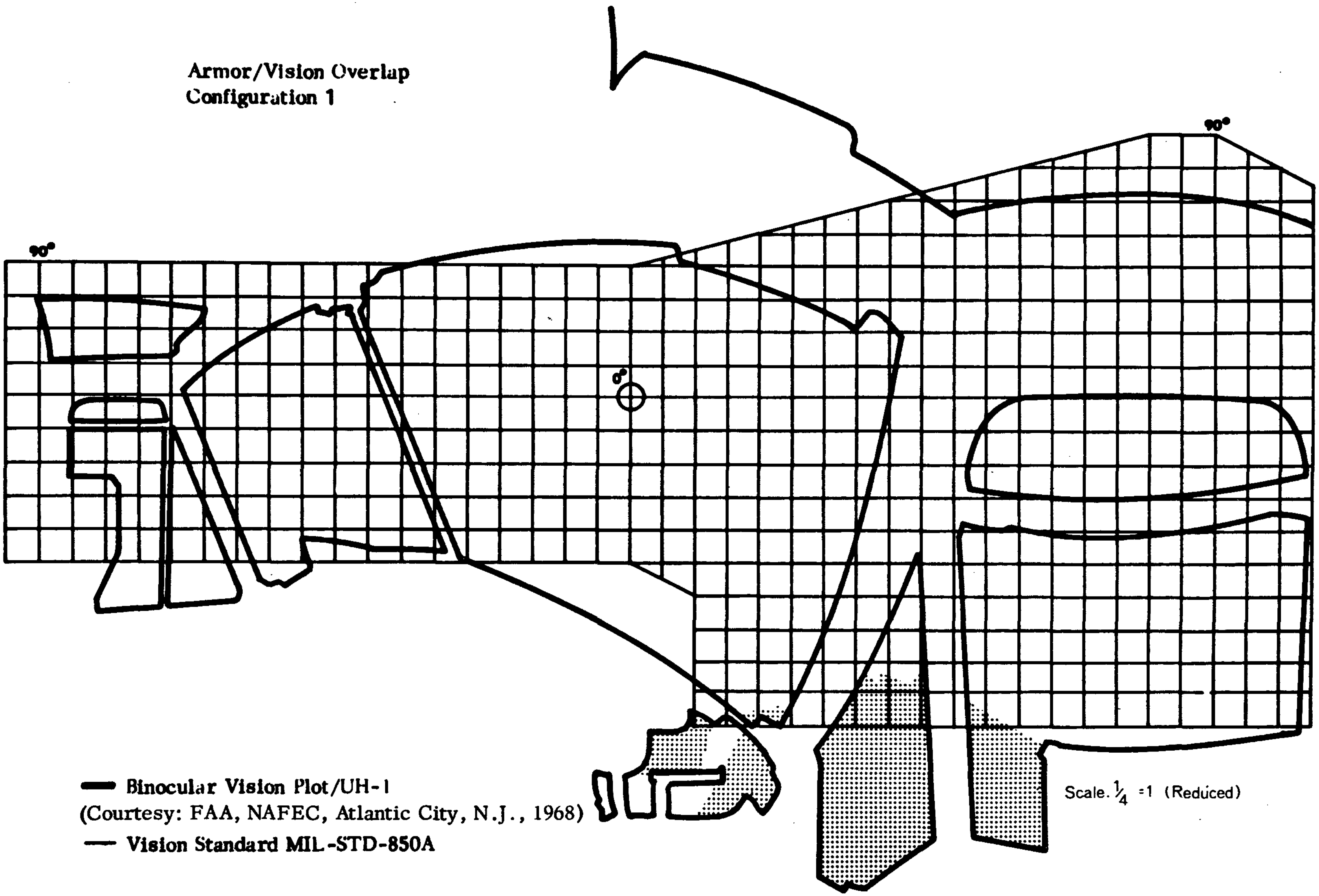

Fig. 41b. CONFIGURATION 1, VISION STANDARD/ARMOR OVERLAP

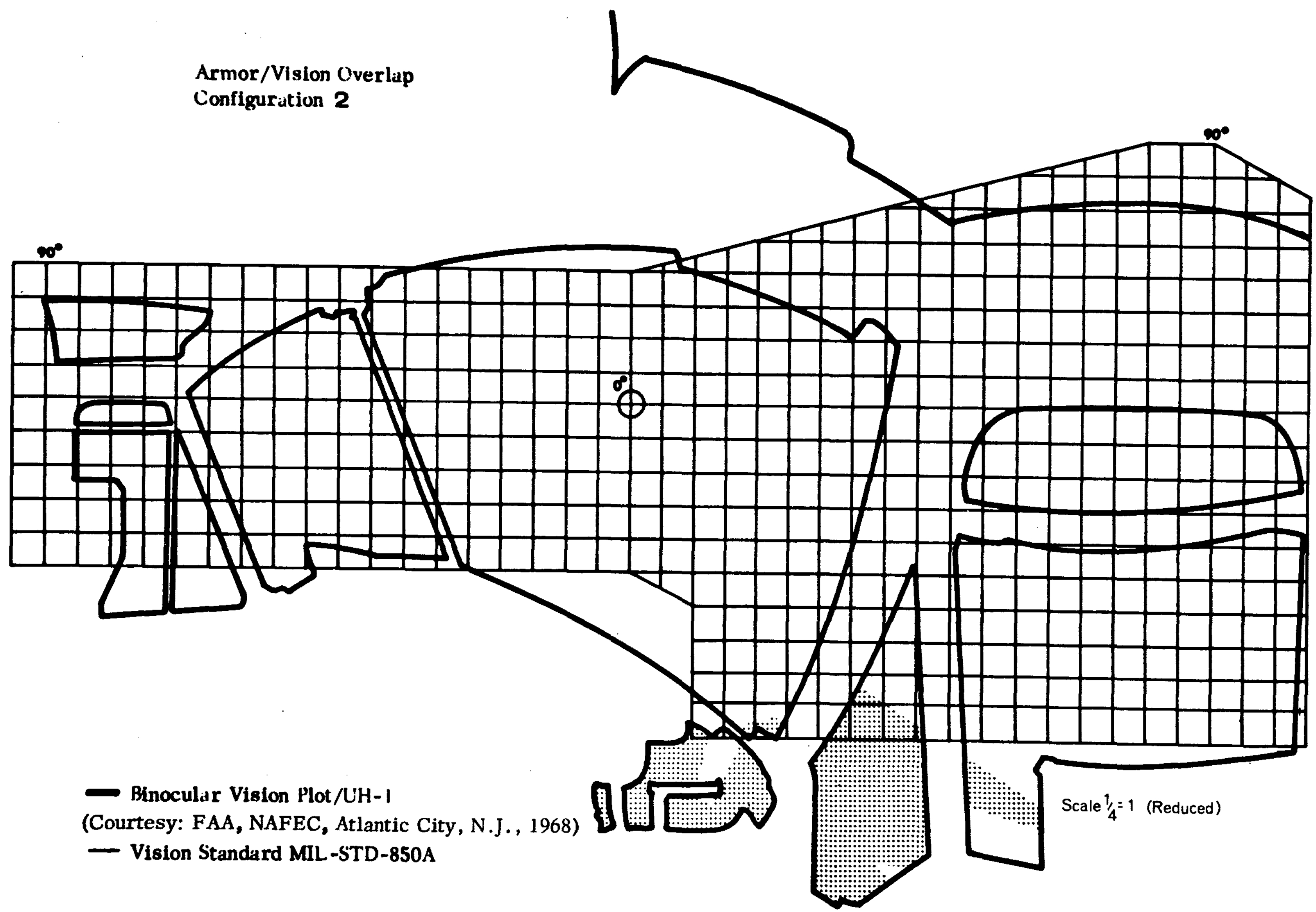

Fig. 42. CONFIGURATION 2, VISION STANDARD/ARMOR OVERLAP

d. Change in the crew motion envelopes due to armor additions (ΔME_K)

As part of the input data necessary to initiate Phase III, a 5th/95th crewman maximum motion envelope is generated as in guideline Phase II. The maximum motion envelope, however, will contain two distinct envelopes:

Non-critical mission tasks motions.

Critical 90% time mission task motions related to the aircraft's flight controls.

It is assumed that the critical 90% time motion envelope must not be infringed upon since it represents those motions essential to the aircraft's mission. With this assumption, the amount of change in the crew motion envelope due to a proposed armor system is expressed as the percent of non-critical motion envelope that is violated by the armor system. Although the non-critical motion envelope represents a small percentage of the total mission time (radio usage, weapons selection, etc.), the crewman must maintain the ability to perform these tasks with a minimum of interference. The final motion envelope change evaluation, then, should be based on a mockup of the proposed armor system to insure that all mission-critical controls can be used and that emergency egress procedures can be properly executed.

Example:

The UH-1 pilot's maximum motion envelope containing his critical and non-critical motion envelopes were included on the engineering drawings prepared for use with the computer-directed drawing instrument. With this data available as a constant remainder, infringements on the crewman's critical motion envelopes can be eliminated. For evaluation purposes, a grid (1/10 = 1) is superimposed on the motion envelope drawings (1/10 = 1), and the following formula used to determine the amount of non-critical motion envelope infringement:

$$\frac{\text{Grid Units Overlapped}}{\text{Total Grid Units Contained in the Non-Critical Envelope}} = \text{Percentage of Non-Critical Envelope Grid Units Overlapped}$$

Configuration 1. Figure 43 presents the UH-1 pilot's maximum motion envelopes in conjunction with armor Configuration 1 and indicates that no motion envelope interference would result from these armor additions.

Configuration 2. Figure 44 presents the UH-1 pilot's maximum motion envelopes in conjunction with armor Configuration 2 and indicates that no motion envelope interference would result from these armor additions.

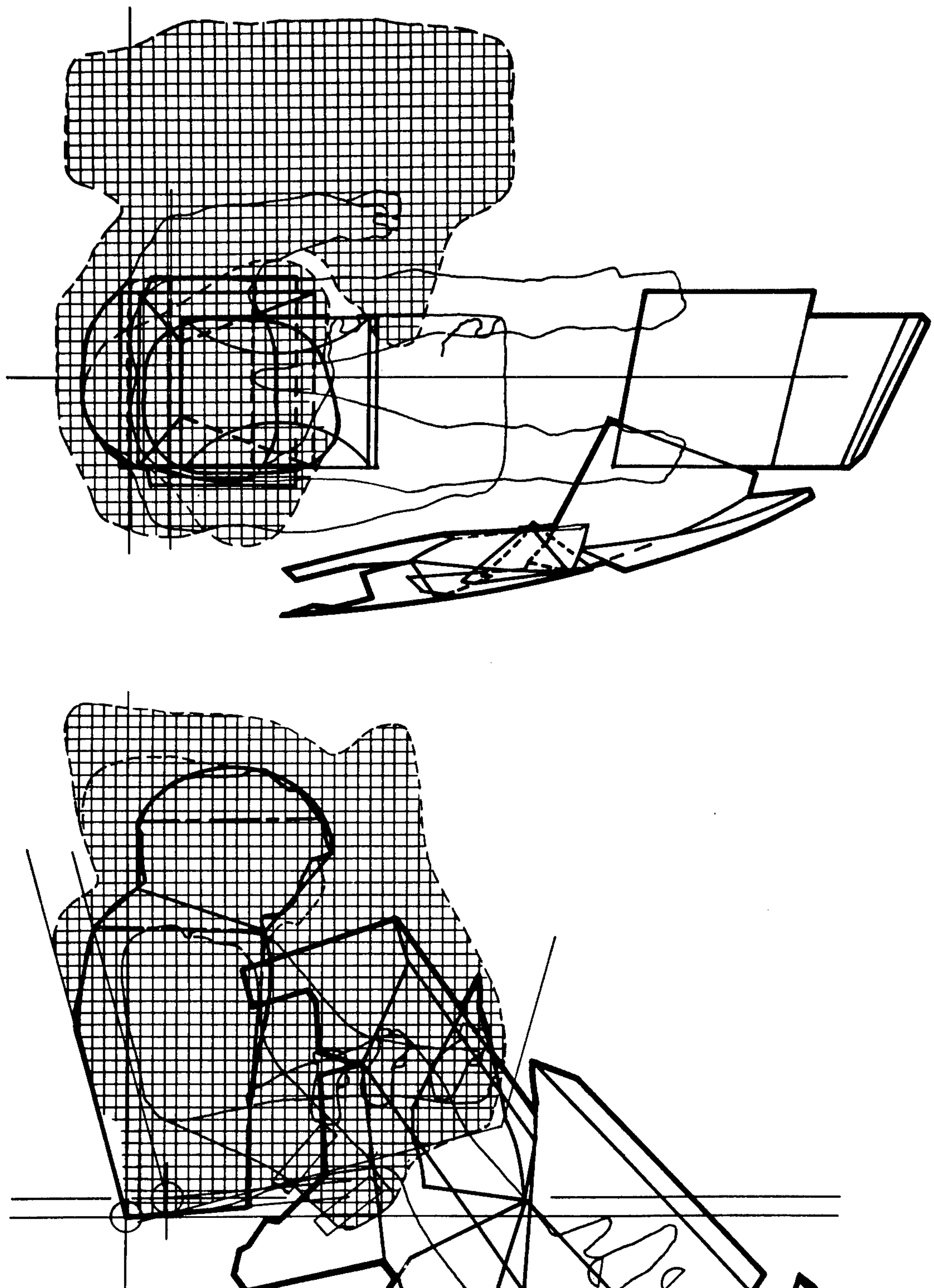

Fig. 43. CONFIGURATION 1, MOTION ENVELOPE/ARMOR INTERFERENCE

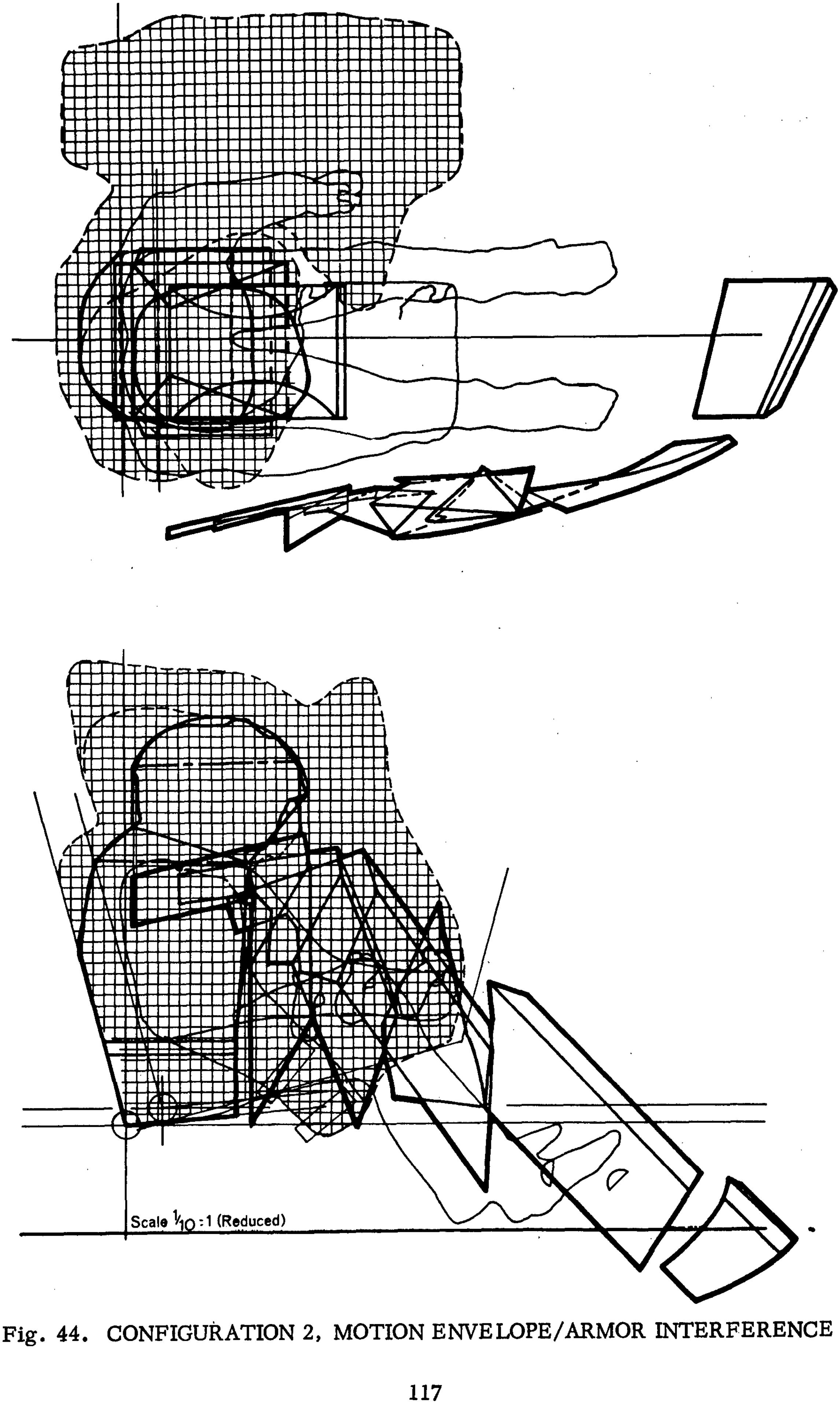

Fig. 44. CONFIGURATION 2, MOTION ENVELOPE/ARMOR INTERFERENCE

SECTION III. GUIDELINE OUTPUT: OPTIMUM ARMOR CONFIGURATION

Using the computational methods outlined in Section II, the various system parameters and weighting factors are applied to the proposed armor configurations. That system which produces the most positive change in system Parameter 1 (crew protection) and the least negative change in system Parameters 2 through 4 (system weight, crew vision and motion envelopes) would be considered the optimum system for the specific conditions stipulated in the study.

Example:

Summing the Δ's in the manner described, the system changes reflected in each example armor configuration are presented in Tables 14 and 15.

Assuming that the weighting factors for each parameter are equal (i.e., all equal 1/4):

TABLE 14

Change in System Parameters Index for Configuration 1

System Parameters	Weighting Factors	Total Change
1 ΔCP_K (236.7)	25%	5.9175
2 ΔW_K (1.0)	25	25.00
3 ΔV_K (0.0088)	25	0.22
4 ΔME_K (0)	25	0
TOTAL Change in Δs 2 thru 4		25.220

TABLE 15

Change in System Parameters Index for Configuration 2

System Parameters	Weighting Factors	Total Change
1 $\Delta\ CP_K$ (394.5*)	25%	9.8625
2 $\Delta\ W_K$ (0.73)	25	18.25
3 $\Delta\ V_K$ (0.0058)	25	0.1450
4 $\Delta\ ME_K$ (0)	25	0
TOTAL Change in Δs 2 thru 4		18.395

*This figure does not include additional body-part/directions covered by the torso armor which is part of this configuration.

The results of these computations indicate that Configuration 2 would be considered the optimum armor configuration for the conditions stipulated throughout the study example.

CONCLUSIONS AND RECOMMENDATIONS

An armor systems specification section should be included in proposals for design of new U. S. Army combat aircraft. The Armor Systems Development/ Evaluation Guideline, if used as a contractual document, would provide the following:

a. A method for insuring timely integration of the armor system with the overall crew-station subsystem.

b. Assures proper integration of the various armor components (body, seat, aircraft) to achieve maximum protection, minimum overlap.

c. Promotes the inclusion of human factors criteria in the armor system design process resulting in a safer, more effective system, thereby increasing user acceptance.

d. Provides criteria for demonstrating the overall effectiveness of the proposed armor system.

e. Provides a uniform basis for submitting armor systems design data.

f. Provides the procuring activity with criteria for adjudication during crew station/armor system mockup evaluation.

g. Allows armor-system shortcomings to be more readily isolated and subsequently improved through the use of appropriate detailed design requirements.

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APPENDIX A

MISSION-ORIENTED CREW ACTIVITY ANALYSIS

UH-1C ARMED HELICOPTER MISSIONS

IFR	Additional Navigational Equipment On Board

1. Assure required navigation equipment is on board.
2. Insure all equipment is operational.

VFR	Prepare Aircraft

1. Load and service aircraft.
2. Perform checks and inspections:
   a. Daily inspections
   b. Special inspections as required
   c. Periodic inspections (each 100 flight hours).
3. Perform scheduled and unscheduled maintenance.
4. Check out and operate all systems.
5. Calibrate, align, and test instruments.
6. Supply, maintain, and issue crew flight equipment.
7. Provide auxiliary power and fuel service.

Night	Additional External Lighting as Required
IFR	Field Lighting as Required

1. Lighted T.
2. Searchlights, beacons, marked lights, etc.

VFR	Prepare Crew

1. Mission intelligence briefing (issue operations order).
2. Obtain charts, flight plans, and navigation aids.
3. Provide transportation and airfield crew facilities.

VFR	Board Aircraft

1. Monitor aircraft loading.
2. Perform walk-around inspection of the aircraft.
3. Board aircraft and secure doors, seat, crew, etc.

VFR Start Engine

1. Use external power as required to start aircraft.
2. Post a fire guard.
3. Visually inspect to make sure personnel and ground equipment are clear of blade.
4. Review "before start" check list.
5. Engage starter.
6. Monitor engine instruments to insure proper start.

IFR Navigation Equipment Check and Navigation Lights On

1. Place aircraft receivers in "ON" position.
2. Fine-tune station frequency.
3. Identify station signal in headset.
4. Perform ADF manual loop and ADF heading system cross-check.
5. ADF system and panel controls positioned as required.

VFR Check Out All Systems

1. Perform engine run-up test.
2. Check hydraulic system, SASS system, electrical system.

Night Navigation Lights On

1. Verify status of lights with outside observer.

VFR Establish Communications For Taxi Clearance

1. Select transceiver frequency.
2. Give:
   a. Identification
   b. Position
   c. Request for taxi clearance.
3. Receive clearance and terminate communication.

Night Field Lighting On

VFR Taxi to Take-Off Positions, Check Systems

1. Lift the aircraft until skids are two to three feet off the ground.
2. Maneuver aircraft to take-off area.

IFR Receive Departure Clearance

1. Obtain take-off and route instructions from flight control.
2. Acknowledge instructions, terminate transmission.

VFR Receive and Acknowledge Clearance

1. Communicate with control using the proper radio procedures, activate flight plan, and receive wind and weather conditions.
2. Terminate communications.

IFR Take-Off and Climb to Assigned Altitude and Heading

1. Set heading on heading indicator and adjust horizon bar on attitude indicator.
2. Apply friction to the collective pitch control to minimize over-controlling.
3. Take-off and maintain heading while climbing to desired position at 70K and 500 FPM rate of climb.
4. Monitor instruments during take-off.

VFR Take-Off and Hold 2'-3' Altitude

1. Take-off by increasing the collective until the aircraft is two to three feet off the ground.
2. Test the cyclic, collective and rudder pedals.
3. Monitor systems by instruments and sound.

IFR Use Radar or Decca to VFR Rendezvous Point

1. Check Decca plotter to locate aircraft position.
2. Use radio to obtain radar fix for cross-check indicated Decca position.

VFR Climb to Rendezvous With Escort Aircraft

1. Increase collective, maintain climb attitude and heading, and climb to rendezvous point.
2. Look for approaching escort aircraft.

Night Identify Lights on Escort Aircraft

1. Identify flash code from approaching aircraft.
2. Return flash code with utility light.
3. Join up with escort aircraft.

IFR	Navigation Calculations as Required	

IFR — Navigation Calculations as Required

1. Obtain Decca, radar, or IFF beacon fix.
2. Update position and ETA destination/checkpoint.

VFR — Visual Fix on Aircraft and Depart Area

1. Visually locate escort aircraft.
2. Communicate with approaching aircraft, join formation, and depart area on proper heading.

Night — Visual or Radio Fix on Approaching Aircraft

1. Identify approaching aircraft lights.
2. Communicate with approaching aircraft, verify proper call signs and radio procedure.
3. Join formation; depart area on proper heading.

IFR — Communicate Status and Verify IFF

1. Initiate interrogation mode of transponder (AN/APX-44).
2. Communicate with flight control to verify that signal is received and audible.
3. Give mission status and next check point.
4. Terminate the communication.

VFR — Verify IFF

1. Initiate interrogation mode of transponder (AN/APX-44).
2. Communicate flight control to establish IFF received and audible.

IFR — Navigation Fix by Decca or Radio

1. Check Decca plotter to locate aircraft position.
2. Also use transponder when passing over check points for position identification as follows:
   a. Select transmit/identification mode.
   b. On completion of transmission, release the I/P switch.

VFR — Dead-Reckoning Navigation

1. Control aircraft airspeed, altitude and heading during specific time intervals while integrating ground position data.

IFR Maintain Altitude, Heading, Identify Position with Transponder

1. Reference IFR Navigation Fix by Decca or Radio for position identification.

VFR Establish Communications with Pathfinder Group

1. Insure proper frequency and communicate with Pathfinder group.
2. Assure authentication and use of ground station, then terminate communications.

IFR Decca Position Check of Non-Directional Radio Passage

1. Check Decca plotter to locate aircraft position.
2. Observe swing of relative bearing needle during station passage.
3. Update navigation data and communicate status.

VFR Visual Fix on FEBA and Communicate Status

1. Communicate with flight control, giving identification, position, and next check point.

Night Visual or Radio/Radar Fix

1. Visual--observe ground features, cross-check map, and update navigation data.
2. Radio--use ADF and FM homing indicator for intercept bearing fix.
3. Radar--climb, request radar fix from flight control.
4. Update navigation.

VFR Arm Weapons and Post Security

1. Place weapons firing switch in "ARMED" position.
2. Position sights, slew guns for proper operation.

IFR Station Arrival, Decca/Radar Fix, Communicate Status

1. Refer to Decca Position Check of Non-Directional Radio Passage.

VFR Establish Communications with Support Units

1. Contact supported unit to coordinate utilization of aircraft in ground action.

IFR	Establish Holding Pattern Over Radio Station	

IFR — Establish Holding Pattern Over Radio Station

1. Using ADF for bearing and station passage indicator, fly standard holding pattern, correcting for winds.
2. Communicate status as required.

VFR — Loiter in Area at Slow Cruise

1. Post security watch.
2. Bring the aircraft to slow flight to obtain maximum endurance from fuel.
3. Monitor flight and engine instruments.
4. Communicate with flight control as required.

VFR — Receive Request for Direct Support Fire

1. Authenticate request.
2. Plot support position and plan routing.

IFR — Depart Area, Navigate to Unit's Position

1. Use Decca or IFF transponder fix to periodically update navigation.
2. Refer to IFR Navigation Fix by Decca or Radio.

VFR — Navigate to Unit's Position

1. By use of dead-reckoning navigation and required instruments, proceed to unit's area.

IFR — Decca Fix on Unit

1. Check Decca plotter to locate aircraft position.
2. Update navigation.
3. Alter course to unit's position.

VFR — Visual Fix on Unit; Communicate with Unit

1. Observe ground features, plot position.
2. Establish communication (light signals or radio depending on security).

VFR	Issue Fire Command	
	1. Give directions of fire and target approach to each crew member. 2. Determine types of fire to be delivered. 3. Anticipate mission and enemy activity.	
IFR	Descend to VFR Conditions; Cancel IFR Clearance	
	1. Descend below cloud cover and orient aircraft's position. 2. Notify instrument control agency of departure from IFR flight.	
VFR	Descend to Mission Altitude	
	1. Decrease collective pitch (engine RPM 6400 to 6600). 2. Establish constant 8-10° angle of descent. 3. Decrease airspeed as descent is made. 4. Monitor flight and engine instruments. 5. Increase collective at mission altitude; observe obstacles.	
Night	Launch or Request Aerial Flare	
	1. Alert crew to prepare for manual flare launch. 2. Maneuver aircraft to launch position. 3. Launch flare; maneuver aircraft into search pattern. 4. Augment flare by searchlight as required.	
VFR	Deliver Requested Fire Support (Rockets)	
	1. Place armament selector switch in "2.75" position. 2. Place rocket-pair selector switch on number of rockets to be fired. 3. Use (XM 60) sight to fix target. 4. Fly a target-collison course. 5. Fire systems, using the cyclic firing switch.	
Night	Target Positioned by Ground Tracer Fire	
	1. Request that ground unit deliver tracer fire to enemy position. 2. Maneuver aircraft to tracer path and deliver fire on target.	

VFR Lift Fire and Provide Security

1. Communicate with ground unit to determine target damage.
2. Fly around target area at a minimum safe altitude watching for enemy activity.
3. Place all firing switches in "SAFE" position.

VFR Communicate Status with Ground Unit

1. Terminate fire-support mission; request instructions from flight control.

IFR Request IFR Clearance; Climb to Assigned Altitude

1. Obtain IFR flight instructions from flight control.
2. Climb to assigned position and heading at maximum safe airspeed (70K) and climb rate (500 FPM).

VFR Navigate to On Call Position

1. Fix present position, plan new routing.
2. Perform dead-reckoning navigation, reference VFR Dead-Reckoning Navigation.

IFR Arrive Destination and Establish Holding Pattern

1. Obtain IFF transponder fix to verify "ON STATION" position.
2. Using ADF for bearing, perform standard holding pattern, correcting for crosswinds.

VFR Visual Fix--Communicate Status

1. Reference VFR Visual Fix on FEBA and Communicate Status.

IFR Maintain Holding Pattern and Request Let Down Clearance

1. Continue time checks and wind corrections while communicating with flight control.
2. Receive vector for descent to VFR.
3. Terminate communications.

VFR Slow Cruise in Area

1. Cruise area awaiting mission and maintain slow-flight power setting for maximum endurance of fuel.

IFR	Descend to VFR Altitude and Cancel IFR

1. Descend below cloud cover, using 500 FPM rate of descent; manitain constant airspeed and aircraft attitude.
2. Orient aircraft, using outstanding ground features.

VFR	Receive Area Recon Mission

1. Establish communication with flight control.
2. Receive area recon mission, authenticate transmission.
3. Plan pattern for reconnoitering area.

Night	Orient Position Over Area

1. Orient position, comparing features on map to actual ground features.
2. Periodically monitor altimeter and map to insure sufficient ground clearance.
3. Maintain visual reference with ground features and obstructions.

VFR	Initiate Recon by Fire (Rockets) and Maneuver

1. Place gun-selector switch in "ALL" position.
2. Place armament selector switch in "2.75" position.
3. Place "off-safe-armed" switch in "ARMED" position.
4. Determine target approach.
5. Maneuver aircraft to target, use gun sight to determine slant range and target centering.
6. Fire systems, using cyclic firing switch.
7. Maneuver aircraft out of area.

Night	Launch Flare or Use Night Lighting Devices

1. Reference Night Launch or Request Aerial Flare.

VFR	Loiter in Area - No Enemy Fire Returned

1. Fly evasive pattern in area.
2. Watch for any signs of enemy activity or gun fire.

Night	Observe for Enemy Ground Flashes and/or Movement

1. Turn off aircraft external lights.
2. Fly orbit of area.
3. Watch for ground flashes.

VFR Continue Recon by Fire and Maneuver

1. Reference VFR Initiate Recon by Fire (Rockets) and Maneuver.

VFR Enemy Fire Drawn - Attack Target

1. Take evasive action, maneuver to avoid ground fire.
2. Repeat functions of VFR Initiate Recon by Fire (Rockets) and Maneuver.

Night Attack Target Area Marked by Ground Fire

1. Reference VFR Initiate Recon by Fire (Rockets) and Maneuver.

IFR IFR Clearance - Report Status

1. Establish communication with flight control--may require altitude change and/or radio relay.
2. Receive and acknowledge routing, altitude, and departure.
3. Update navigation and plan new routing.

VFR Communicate Status and Receive Truck Escort Mission

1. Reference VFR Receive Area Recon Mission.

IFR Radar/Decca Fix; Climb to Assigned Altitude

1. Obtain IFF transponder or Decca fix (reference IFR Navigation Fix by Decca or Radio).

VFR Descend to Mission Altitude

1. Ascend 500 FPM; airspeed 60K+(reference VFR Climb to Rendezvous With Escort Aircraft.

IFR Arrival Convoy--Pathfinder Fix

1. Receive radio bearing from aircraft position to unit's position.
2. Fly the radar vector and communicate with pathfinder group.
3. Authenticate transmission.
4. Communicate with convoy commander.
5. Terminate communication after receiving mission and intended route of convoy.

VFR	Dead-Reckoning Navigation to Rendezvous

1. Reference VFR Dead-Reckoning Navigation.

IFR	Cancel IFR Clearance, Descend to VFR Altitude

1. Reference IFR Descend to VFR Conditions; Cancel IFR Clearance.

VFR	Visual Fix Column and Communicate with Unit.

1. Refer to IFR Arrival Convoy--Pathfinder Fix for communication between aircraft and unit commander.

Night	Visual Fix Convoy with Infrared Scope

1. Use one of the following to identify column:
   a. Man-held sniper scope.
   b. Searchlight.
   c. Code light signals.

VFR	Fly Orbiting Path over Column

1. Fly forward of column and orbit back watching for possible enemy attack areas or enemy activity.
2. Monitor road conditions to front of convoy.
3. Maintain radio contact with convoy commander.

VFR	Communicate with Column; They Request Landing for Coordination

1. Acknowledge landing request.
2. Aircraft and field commander make joint decision regarding landing site.

Night	Request Landing Area and Ground Lighting

1. Request area for landing and ground guides.
2. Request marker lights for landing position.

VFR	Prepare for Landing - Communicate Status

1. Insure air cover from the other helicopter in the fire team.
2. Alert crew of descent.
3. Evaluate landing site on descent.
4. Communicate with base, informing flight control of planned landing.

Night	Orient Aircraft with Ground Lighting Markers for Landing

1. Control descent so as to clear any obstacles.
2. Orient aircraft with markers.
3. Monitor airspeed indicator and altimeter.

VFR	Land Aircraft

1. Make normal 8^{o}-10^{o} approach.
2. Coordinate the reduction of collective pitch with lateral cyclic until the skids touch the ground.
3. Bring engine to idle RPM.

Night	Landing Lights as Required

1. Use searchlight if required.
2. Use landing lights also when required.
3. If ground marker lights are used, land aircraft with right skid slightly to the left of marker lights.

VFR	Crew Member Assures Equipment Readiness, Debark Aircraft

1. Pilot debarks aircraft.
2. Gunner-copilot maintains engine idle and monitors instruments.
3. Crew chief provides flank security with door gun.

VFR	Prepare for Take-Off

1. Bring engine RPM up to 6600.
2. Alert crew of maximum performance take-off.
3. Monitor engine instruments as the RPM builds.
4. Observe for obstructions in take-off path.

Night	Identify Obstructions

1. Evaluate possible obstructions.
2. Decide best route of departure.

VFR Maximum Performance Take-Off

1. Place cyclic in neutral position.
2. Place throttle full open while increasing collective.
3. As the helicopter leaves the ground, continue increasing power to maximum available torque.
4. Bring aircraft to at least a 40K airspeed attitude.
5. Maintain aircraft heading while building power.
6. When sufficient altitude for obstacles clearance is obtained, increase collective and reduce power to establish a normal climb.

Night Landing and Searchlight as Required

1. To monitor obstructions and route of departure, turn on searchlights.
2. Use the landing lights if also required.

VFR Communicate Status and Rejoin Fire Team

1. Communicate with fire team.
2. Join up slowing ascend in order for fire team to form on aircraft.
3. Change frequency and communicate with flight control.

IFR Request IFR Clearance; Climb to Assigned Altitude and Heading

1. Reference IFR Request IFR Clearance; Climb to Assigned Altitude.

VFR Abandon Escort Mission

1. Communicate with convoy commander and terminate escort mission.
2. Change frequency and communicate with flight control for further orders.

IFR Pathfinder Fix - Request Let Down Clearance

1. Communicate with Pathfinders in area for vector to area.
2. Obtain vector from aircraft position to recon area.
3. Fly vector by time/distance method.
4. Communicate flight control for let-down clearance.

VFR Navigate to Recon Area

1. Dead-reckoning navigation (reference VFR Dead-Reckoning Navigation).

Night	Time/Distance/Heading Checks	

Night — Time/Distance/Heading Checks

1. Monitor clock, ground track, and map location to insure proper position of aircraft.

IFR — Descend to VFR - Cancel IFR Clearance

1. Descend below cloud cover and orient position with ground features.
2. Notify flight control of departure from IFR flight.

VFR — Visual Fix on Recon Area

1. Visual locate recon area.
2. Check ground features with map to insure proper area.

Night — Visual Fix; Radio/Radar Fix - Use Landing Light of Request Flare

1. Refer to Night Visual or Radio/Radar Fix and IFR Decca Position Check of Non-Directional Radio Passage for radio/radar/Decca fix.

VFR — Communicate Status

1. Communicate with flight control, giving position and intentions.
2. Maintain contact for relay on recon information.

VFR — Prepare to Recon Area

1. Plan search pattern.
2. Monitor instruments.
3. Inform crew members of areas of responsibility.

VFR — Initiate Area Recon

1. Fly appropriate time/distance/headings of the search pattern legs earlier planned.
2. Record any observations.

Night — Time/Distance/Heading Checks

1. Reference Night Time/Distance/Heading Checks.

VFR — Visual Fix Recompute Heading/Distance

1. Orient aircraft to ground by comparison of maps and ground features.

Night	Visual or Radio/Radar Fix
	1. Reference Night Visual or Radio/Radar Fix.
VFR	Complete Recon of Area
	1. Continue flight of planned recon pattern. 2. Communicate information to flight control.
IFR	IFR Clearance to Survey Area
	1. Contact flight control for instrument flight. 2. Receive clearance and turn on assigned heading. 3. Maintain contact in order to relay findings.
VFR	Receive Request for Radiological Survey of Recon Area
	1. Communicate with flight control and receive survey mission. 2. Plan survey path. 3. Maintain contact with flight control.
Night	Launch Flare as Required to Survey Area
	1. Reference Night Launch Flare or Use Night Lighting Devices.
IFR	Communicate Status, Descend to 500' Plan Search Pattern
	1. Communicate with flight control, giving intentions, and request radar track of survey path. 2. Plan survey path. 3. Descend to survey altitude.
VFR	Descend to 500' - Cruise 60K
	1. Reference VFR Descend to Mission Altitude.
IFR	Fly Appropriate Time/Distance/Heading Legs of Search Pattern - Record Data
	1. Reference VFR Fly Across Area Taking Readings Every 15 Seconds.

VFR Fly Across Area Taking Readings Every 15 Seconds

1. Fly 500' absolute altitude and an airspeed of 60K.
2. Fly survey course taking care not to round corners.
3. Monitor instruments carefully.
4. Maintain observation for any ground activity.

IFR Fly Holding Pattern

1. Bring aircraft to slow flight.
2. Fly a standard holding pattern.
3. Contact flight control, relaying data from survey.

VFR Communicate Findings

1. Contact flight control.
2. Relay data from survey.
3. Receive route recon in area.
4. Terminate communication.

VFR Cruise Along Route

1. Fly to route and orient map with terrain.
2. Fly route, changing airspeed and altitude as determined necessary to observe key feature of route.
3. Insure cover from other fire team member.
4. Maintain constant contact with team member.
5. Insure crew members are maintaining flank security.

VFR Recon Road

1. Evaluate bridges, road surfaces, curves and any steep grades.
2. Monitor instruments and maintain orientation.
3. Maintain security.

Night Time/Distance Checks

1. Use searchlight as required.
2. Maintain location and orientation checks with maps.

VFR Communicate Status

1. Communicate with flight control.
2. Give finding of route recon.
3. Request return to base.
4. Terminate communication.

IFR	Establish Radio Communications for IFR Control	

IFR — Establish Radio Communications for IFR Control

1. Contact flight control request IFR flight.
2. Establish use of Decca or radio beacon.
3. Refer to IFR Navigation Fix by Decca or Radio and IFR Decca Position Check of Non-Directional Radio Passage for proper procedures for Decca and beacon use.

VFR — Depart Area for FEBA

1. Bring aircraft to proper return heading.
2. Maintain security and monitor terrain and instruments.

IFR — Navigate Using FM Homing

1. Contact FM homing station, authenticate transmission.
2. Using (AN/ARC-44), place home switch to "ON" position.
3. Track signal received in the interphone system.
4. Monitor beacon indicator and fly monitor needle position.

VFR — Navigate Visual and Pathfinder Fix

1. Contact Pathfinder team in area.
2. Use transponder and receive fix from the Pathfinder team by radio.
3. Constantly monitor terrain and orient map and terrain.

Night — Time/Distance Checks

1. Monitor clock, ground track, and map location to insure proper position of aircraft.

VFR — Communicate Status

1. Communicate with flight control, giving location and ETA.

IFR — Radar/Decca Fix

1. Refer to Night Visual or Radio/Radar Fix and IFR Decca Position Check of Non-Directional Radio Passagefor procedure for radar/Decca fix.

VFR — Visual Fix or Pathfinder Route Checkpoint

1. Communicate with Pathfinder team in area and authenticate transmission.
2. Use transponder over checkpoint to locate position.

3. Receive fix by radio from Pathfinder team.
4. Terminate communications.

Night Visual or Radio/Radar Fix

1. Refer to Night Visual or Radio/Radar Fix and IFR Decca Position Check of Non-Directional Radio Passage for procedure for radio/radar/ Decca fix.

VFR Communicate Status

1. Communicate with flight control, giving position, identification, and updated ETA.

VFR Continue Dead-Reckoning Navigation to FEBA

1. Refer to VFR Dead-Reckoning Navigation for procedures.

IFR Decca/Radio/Radar Fix

1. For Decca/radio/radar fix procedures, refer to Night Visual or Radio/Radar Fix and IFR Decca Position Check of Non-Directional Radio Passage.

VFR Visual Fix of FEBA

1. Monitor terrain and map.
2. Visually locate FEBA on ground.
3. Recheck map orientation with predominant terrain features.

Night Visual/Radio/Radar Fix

1. For radio/radar fix procedures, refer to IFR Decca Position Check of Non-Directional Radio Passage or Night Visual or Radio/Radar Fix.

VFR Communicate Status - Receive External Load Mission

1. Communicate with flight control, giving identification, ETA and location.
2. Receive mission.
3. Request heading.
4. Terminate communications.

VFR	Communicate with Pickup Unit	

VFR   Communicate with Pickup Unit

1. Change frequency to pickup unit's frequency.
2. Communicate with unit commander and receive homing frequency.

IFR   Radio Beacon Homing (AN/ARC-54)

1. Tune to frequency of homer station.
2. Identify station by voice procedures.
3. Place mode selector in the "HOME" position.
4. Monitor OMNI needles.
5. Fly aircraft with OMNI needles and heading guide.

VFR   Navigate to Unit's Position

1. Use dead-reckoning navigation and ref to VFR Dead-Reckoning Navigation for procedure.

IFR   Radio Passage - Communicate Status

1. Communicate with ground unit.
2. Monitor needles; when it reverses direction, the homing station has been passed.
3. Maintain position and communicate with station and identicate position.
4. Request landing instructions and lighting.

VFR   Visual Fix on Pickup Area

1. Refer to Night Visual or Radio/Radar Fix(1).

Night   Visual or Radio Beacon Fix

1. Refer to Night Visual or Radio/Radar Fix (1)(2).

IFR   Cancel IFR - Descend to VFR Altitude

1. Communicate with flight control to request return to VFR flight.
2. Receive instruction for flight to cloud cover break-through.
3. Terminate communications.

VFR	Visual Fix Ground Personnel	

VFR — Visual Fix Ground Personnel

1. Refer to VFR Visual Fix on Unit; Communicate with Unit.

VFR — Communicate with Ground Personnel

1. Insure proper frequency and communicate with ground personnel.
2. Authenticate transmission.
3. Request information about terrain around pickup area.
4. Maintain contact.

Night — Request Lighting of Load

1. Request lighting of pickup area.
2. Use landing, search, and utility lights as needed.

VFR — Make Approach

1. Make a normal approach with a sufficient angle to clear any obstructions.
2. Place cargo hook arming switch to "ON" position.
3. Key the "FM" transmitter to dissipate accumulated static electricity.

VFR — Hook Up Load

1. Watch signalman for any maneuvering directions in order to be directly over the load.
2. Hover aircraft over load while hook-up man attaches rope to cargo hook.

IFR — Establish IFR Flight

1. Change frequency and communicate to flight control to establish IFR flight.
2. Change frequency back to pickup unit's frequency and estimate contact.

VFR — Lift Load and Climb to Mission Altitude

1. Lift aircraft until the load is felt on the aircraft.
2. Place cargo release switch in the "OFF" position.
3. Depress the electrical cargo release button, both pilot's and copilot's.
4. Place cargo release in the "ARM" position and climb out to cruise altitude.

IFR	Navigate By Use of Radio Beacon 1. For homing procedure, refer to IFR Radio Beacon Homing (AN/ARC-54).
VFR	Cruise to Unloading Zone 1. Dead-reckoning navigation, refer to VFR Dead-Reckoning Navigation.
Night	Time/Distance Checks 1. Monitor clock, ground track, and map location to insure proper position of aircraft.
IFR	Cancel IFR Descend to VFR 1. Descend below cloud cover and orient aircraft position. 2. Notify instrument control of departure from IFR flight.
VFR	Visual Fix Unloading Area 1. Refer to VFR Visual Fix on Unit; Communicate with Unit (1).
Night	Visual or Radio Fix on Area 1. Refer to IFR Decca Position Check of Non-Directional Radio Passage and Night Visual or Radio/Radar Fix.
VFR	Make Approach on Unloading Area 1. Take up normal approach angle and counter any swing of load under the aircraft. 2. Evaluate the unloading zone conditions and hover over release point. 3. Monitor airspeed indicator and altimeter.
Night	Request Lighting If Required 1. Communicate with ground unit; authenticate transmission. 2. Request lighting of release area. 3. Request information on any terrain obstructions. 4. Use aircraft lights as required. 5. Maintain contact with ground unit.

VFR Descend Until Load Rests On Ground

1. Descend by coordination of cyclic and collective controls until load rests on ground.
2. Monitor signals from ground personnel.
3. Maintain radio contact.

VFR Release Load

1. Release load either by cyclic release button or by manual foot pedal located on right side of aircraft.
2. Communicate with ground unit and terminate mission.

IFR Establish IFR Flight by Communication with Traffic Control

1. Contact flight control and establish IFR flight.
2. Turn onto assigned heading.

VFR Ascend to Communicate with Base

1. Change frequency to base frequency and communicate giving position and ETA.
2. Ascend by increasing collective and maintaining heading.

IFR Navigation to Base (ADF)

1. Tune ADR receiver to station.
2. Identify signal and switch to the ADF operating mode.
3. Track the sending station.
4. Upon crossing the station, report to the controller in landing area.
5. Perform standard right turn and continue let down.

VFR Direct Navigation to Base

1. Dead-reckoning navigation, refer to VFR Dead-Reckoning Navigation.

Night Time/Distance/Heading Checks

1. Refer to Night Time/Distance Checks for procedure.

IFR Beacon Fix - Request Approach Clearance

1. Monitor needle on indicator and maintain control descent until breakout.
2. Contact tower; request approach clearance.

VFR	Visual Fix Base	

VFR Visual Fix Base

1. Refer to VFR Visual Fix on Unit; Communicate with Unit.

IFR Initiate ADF Approach

1. Continue tracking the station while monitoring instruments for proper atitude.
2. Maintain contact with tower for position checks.

VFR Prepare for Landing - Obtain Clearance

1. Evaluate landing approach attitude.
2. Request landing clearance from tower.
3. Monitor altimeter and airspeed indicator.

Night Request Lighting

1. Field lighting as required.
2. Turn landing lights to "ON."

IFR Descend to VFR - Land Aircraft

1. Descend to VFR conditions.
2. Coordinate the reduction of collective pitch with lateral cyclic until skids touch the ground.

VFR Land Aircraft

1. Touch down.
2. Place governor RPM switch to decrease position.
3. Move throttle to flight idle position.
4. Place low RPM switch in "OFF" position.
5. Allow EGT to stabilize.
6. Place fuel in "OFF" position.
7. Place all other switches in "OFF" position.
8. Make accumulator check.
9. Tie down rotor blades.

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APPENDIX B

PERCENTAGE BREAKDOWN PER MISSION PHASE
OF PILOT/COPILOT FUNCTIONS
UH-1C AIRCRAFT*

ARMED HELICOPTER MISSIONS AND REQUIRED PHASES

Escort

1. Takeoff
2. Interception of column
3. Escort of column
4. Security of loading operations
5. Escort to objective
6. Delivery of supporting fires
7. Objective security
8. Escort of column
9. Transit friendly area
10. Landing

Fire Support

1. Takeoff
2. Transit friendly area
3. Transit hostile area
4. Approach target
5. Attack assigned target
6. Transit hostile area
7. Transit friendly area
8. Landing

Reconnaissance and Security

1. Takeoff
2. Transit friendly area
3. Reconnaissance

*Functions may occur simultaneously so that the sum of the discrete function percentages may not equal 100%.

4. Approach target
5. Attack assigned target
6. Reconnaissance
7. Transit friendly area
8. Landing

PHASE: TAKEOFF

Function: Vehicle Control (Manual)

Tasks	Pilot (%)	Copilot (%)
Pre-takeoff check	14.0	14.0
Vertical ascent	2.0	-
Desired heading	15.0	-
Stabilize at a hover	2.0	-
Observe to clear	32.0	32.0
Establish climb	6.0	-
Pitch power adjustment	12.5	-
Airspeed	12.5	-
Power instruments	12.5	-

Function: Navigation (Electrical Instruments)

Tune navigation aids	4.0	-
Crosscheck navigation aids	10.0	-

Function: Communications (Internal)

Readiness statement	2.5	5.0
Statement of clear	-	1.5

Function: Communications (External)

Takeoff information	10.0	-
Flight readiness	5.0	-
Tactical advisory	5.0	-
Qsy tactical frequency	6.0	-

PHASE: TRANSIT FRIENDLY AREA

Function: Vehicle Control (Manual)

Tasks	Pilot (%)	Copilot (%)
Desired heading	17.0	-
Desired altitude	9.0	-
Desired airspeed	4.5	-
Terrain avoidance	-	-
Airborne object separation	-	-

Function: Navigation (Pilotage)

Refer to map	15.5	19.0
Refer to terrain	25.5	34.0

Function: Navigation (Dead Reckoning)

Compute heading	-	6.0
Compute time	-	9.0
Measure distance	-	6.0

Function: Navigation (Electrical Instruments)

Refer to ADF, VOR and/or FM	7.5	2.5

Function: Target Detection (Visual)

Search terrain	24.5	26.5

Function: Target Detection (Electronic)

Audio on (acoustic detector)	2.0	-

Function: Communications (Internal)

Tasks	Pilot (%)	Copilot (%)
Position statements	-	9.0
Area to observe	5.0	-
Aircraft system conditions	4.0	-

Function: Communications (External)

Air to air	7.0	-
Mission information	6.0	-
Flight advisory information	2.5	-
Flight following information	6.5	-

Function: IFF

Transponder on-off	5.0	-
Altitude	2.5	-
Airspeed	2.5	-
Track	2.5	-

PHASE: TRANSIT HOSTILE AREA

Function: Vehicle Control (Manual)

Desired heading	5.0	-
Desired altitude	5.0	-
Desired airspeed	4.0	-
Terrain avoidance	-	-
Airborne object separation	-	-

Function: Navigation (Pilotage)

Refer to map	21.5	24.0
Refer to terrain	33.5	43.5

Function: Navigation (Dead Reckoning)

Tasks	Pilot (%)	Copilot (%)
Compute heading	-	9.0
Compute time	-	9.0
Measure distance	-	6.0

Function: Navigation (Electrical Instruments)

Refer to ADF, VOR and/or FM	7.5	-

Function: Target Detection (Visual)

Search terrain	32.5	49.0

Function: Target Detection (Electronic)

Audio (Acoustic Detector)	-	-

Function: Communications (Internal)

Position statements	2.5	12.0
Area to observe	4.0	-
Aircraft system conditions	5.0	-
Weapon system conditions	-	4.0

Function: Communications (External)

Air to air	4.0	-
Mission information	-	-
Flight following information	-	-

Function: Countermeasures

Fire to test	2.5	4.0
Maneuver	11.0	-
Weapons control	2.5	2.5
Sight positioning	2.0	8.5

PHASE: APPROACH TARGET

Function: Vehicle Control (Manual)

Tasks	Pilot (%)	Copilot (%)
Desired heading	32.5	-
Desried altitude	35.0	-
Desired airspeed	26.5	-
Terrain avoidance	-	-
Airborne object separation	-	-

Function: Navigation (Pilotage)

Refer to map	6.5	4.0
Refer to terrain	45.0	97.0

Function: Target Detection (Visual)

Terrain search	43.5	96.5

Function: Target Detection (Electronic)

Audio (Acoustic Detector)	-	-

Function: Target Identification (Visual)

Observe target	28.5	47.0
Confirm hostile & assigned	8.0	8.0

Function: Target Engagement (Weapons Select)

Decision of ordnance	5.0	-
Selection of ordnance	2.5	2.5
Final weapons system check	3.0	3.0

Function: Target Engagement (Method of Attack)

Tasks	Pilot (%)	Copilot (%)
Decision of altitude	4.0	-
Decision of airspeed	4.0	-
Decision of track	4.0	-
Decision of break procedure	4.0	-

Function: Communications (Internal)

Position statements	2.5	1.0
Five mission statements	8.0	2.5
Final cockpit check	2.5	4.0
Weapons systems condition	2.5	2.5
Target identification	2.0	2.5

Function: Communications (External)

Air to air	5.5	4.0
Mission information	7.5	-

Function: Countermeasures (Weapons)

Control selection	2.5	2.5
Sight positioning	-	-
Maneuver	24.0	-

PHASE: ATTACK ASSIGNED TARGET

Function: Vehicle Control (Manual)

Aircraft track	40.0	-
Altitude	35.0	-
Airspeed	39.5	-
Attitude/trim	50.0	-
Terrain avoidance	11.0	-
Airborne objects separation	4.0	4.0

Function: Navigation (Pilotage)

Tasks	Pilot (%)	Copilot (%)
Refer to map	-	-
Refer to terrain	37.0	4.5

Function: Target Detection (Visual)

Search for other targets	24.0	5.0

Function: Target Detection (Electronic)

Audio (Acoustic Detector)	-	-

Function: Target Identification (Visual)

Observe target	5.0	5.0
Confirm hostile & assigned	5.0	5.0

Function: Target Engagement (Method of Attack)

Attack angle	6.0	-
Aircraft trim	-	-
Aircraft track	9.0	-
Aircraft/target relationship	10.0	7.5
Maneuver to disengage	6.0	-

Function: Target Engagement (Weapons Control)

Sight rockets	22.0	-
Fire rockets	10.0	-
Sight flex 7.62MG	-	37.5
Fire flex 7.62MG	-	14.0
Sight flex 40mm GL	-	10.0
Fire flex 40mm GL	-	3.5

Function: Communications (Internal)

Tasks	Pilot (%)	Copilot (%)
Ordnance delivery statement	5.5	-
Target information	2.5	2.5
Ammunition status	-	-
Aircraft status	-	-

Function: Communications (External)

Tasks	Pilot (%)	Copilot (%)
Air-to-air (2)	7.5	-
Target information	3.5	-

Function: Countermeasures (Weapons)

Tasks	Pilot (%)	Copilot (%)
Control selection (2)	-	7.5
Sight positioning	-	25.0
Weapons firing (flex) 7.62MG	-	15.0
Maneuver	31.0	-

PHASE: LANDING

Function: Vehicle Control (Manual)

Tasks	Pilot (%)	Copilot (%)
Pre-landing check	11.0	11.0
Pitch power adjustment	9.5	-
Approach airspeed	23.5	-
Observe to clear	22.5	41.5
Establish descent	16.0	-
Establish at a hover	3.0	-
Desired track	12.0	-
Vertical descent	4.0	-

Function: Communications (Internal)

Tasks	Pilot (%)	Copilot (%)
Readiness statements	1.5	3.0
Statement of clear	-	7.0
Weapons condition statement	1.5	3.0

Function: Communications (External)

Tasks	Pilot (%)	Copilot (%)
Interrogate Req'd landing frequency	3.0	-
Tactical advisory	4.5	-
Landing information	15.0	-
Flight readiness	4.0	-
Servicing requirements	2.5	-

PHASE: RECONNAISSANCE

Function: Vehicle Control (Manual)

Desired heading	11.0	-
Desired altitude	10.0	-
Desired airspeed	-	-
Terrain avoidance	-	-
Airborne objective separation	-	-

Function: Navigation (Pilotage)

Refer to map	15.0	10.0
Refer to terrain	31.0	74.0

Function: Target Detection (Visual)

Search terrain (2)	38.0	66.5
Record observations	-	17.5

Function: Target Detection (Electronic)

Audio (Acoustic Detector)	-	-

Function: Communications (Internal)

Position statement	12.5	10.0
Area to observe	11.0	10.0
Aircraft systems condition	3.5	-
Weapons systems condition	3.5	-

Function: Communications (External)

Tasks	Pilot (%)	Copilot (%)
Air-to-air (3)	7.5	-
Flight following (4)	3.5	-
Artillery advisory	-	-
Spot reporting	16.0	-

Function: Countermeasures

Maneuver	3.5	-
Weapons control	-	6.5
Sight positioning	-	2.5

MISSION: ESCORT

PHASE: INTERCEPTION OF COLUMN

Function: Vehicle Control (Manual)

Desired heading	12.5	-
Desired altitude	18.5	-
Desired airspeed	9.0	-
Terrain avoidance	-	-
Airborne object separation	9.0	-

Function: Navigation (Pilotage)

Refer to map	11.5	11.0
Refer to terrain	11.5	20.5

Function: Navigation (Dead Reckoning)

Compute heading	-	5.0
Compute time	-	4.0
Measure distance	-	6.0

Function: Navigation (Electronic Inst.)

Tasks	Pilot (%)	Copilot (%)
Refer to ADF, VOR and/or FM	7.0	-

Function: Target Detection

Search terrain	13.0	16.5

Function: Target Detection (Elect.)

Audio (Acoustic Detector)	-	-

Function: Communications (Internal)

Position statements	2.5	5.0
Area to observe	4.0	-
Column identification	5.0	-
Aircraft systems condition	-	-

Function: Communication (External)

Air to air	8.0	-
Mission information	2.5	-
Flight following information	2.5	-
Flight advisory information	2.5	-

Function: IFF

Transponder On-Off	5.0	-
Altitude	4.0	-
Airspeed	2.5	-
Track	2.5	-

Function: Countermeasures

Tasks	Pilot (%)	Copilot (%)
Fire to test	1.0	2.5
Maneuver	12.5	-
Weapons control	4.0	-
Sight positioning	1.5	1.5

PHASE: ESCORT OF COLUMN

Function: Vehicle Control (Manual)

Desired heading	10.0	-
Desired altitude	10.0	-
Desired airspeed	10.0	-
Dash-to search/return (1)	10.0	-
Terrain avoidance	-	-
Airborne object separation	34.0	-

Function: Navigation (Pilotage)

Refer to map	3.5	9.0
Refer to terrain	-	88.0

Function: Navigation (Dead Reckoning)

Compute heading	-	5.0
Compute time	-	5.0
Measure distance	-	5.0

Function: Navigation (Electronic Inst.)

Refer to ADF, VOR and/or FM	-	-

Function: Target Detection (Visual)

Search terrain (2)	-	88.0
Sight positioning	-	88.0

Function: Communications (Internal)

Tasks	Pilot (%)	Copilot (%)
Position statements	1.5	3.5
Weapons systems condition	-	2.5
Area to observe	4.0	-
Aircraft systems condition	-	-

Function: Communications (External)

Air to air (3)	7.5	-
Mission information (5)	3.5	-

PHASE: SECURITY OF LOADING

Function: Vehicle Control (Manual)

Desired heading	7.5	-
Desired altitude	3.5	-
Desired airspeed	3.5	-
Terrain avoidance (1)	-	-
Airborne object separation	-	-

Function: Navigation (Pilotage)

Refer to map	12.5	3.5
Refer to terrain	38.0	46.5

Function: Target Detection (Visual)

Search terrain (2)	38.0	46.5

Function: Communications (Internal)

Position statement	3.5	3.5
Area to observe	6.5	3.5
Aircraft systems condition	-	-
Weapons systems condition	-	-

Function: Communication (External)

Tasks	Pilot (%)	Copilot (%)
Air to air (3)	3.5	-
Mission information (5)	3.5	-
Artillery advisory	3.5	-

Function: Countermeasures

Maneuver	2.5	-
Weapons control	-	-
Sight positioning	-	-

PHASE: ESCORT TO OBJECTIVE

Function: Vehicle Control (Manual)

Desired heading	9.0	-
Desired altitude	9.0	-
Desired airspeed	9.0	-
Dash to search/return	9.0	-
Terrain avoidance (1)	-	-
Airborne object separation	35.0	-

Function: Navigation (Pilotage)

Refer to map	7.5	9.0
Refer to terrain	-	88.0

Function: Navigation (Dead Reckoning)

Compute heading	-	5.0
Compute time	-	5.0
Measure distance	-	5.0

Function: Target Detection (Visual)

Search terrain (2)	-	88.0
Sight positioning	-	88.0

Function: Communications (Internal)

Tasks	Pilot (%)	Copilot (%)
Position statements	-	6.5
Weapons system condition	3.5	5.0
Area to observe	3.5	2.5
Aircraft system condition	-	-

Function: Communications (External)

Air to air	7.5	-
Mission information	5.0	-

PHASE: DELIVERY OF FIRE

Function: Vehicle Control (Manual)

Desired head/track	57.0	-
Desired altitude	46.5	-
Desired airspeed	30.0	-
Attitude/trim	24.0	-
Terrain avoidance	9.0	-
Airborne object separation	5.5	7.5

Function: Navigation (Pilotage)

Refer to map	2.5	-
Refer to terrain	15.0	-

Function: Target Detection (Visual)

Terrain search	30.5	10.5

Function: Target Detection (Elec. Inst.)

Audio (Acoustic Detector)	-	-

Function: Target Identification (Visual)

Tasks	Pilot (%)	Copilot (%)
Observed target	10.0	10.0
Confirm location	6.0	5.5

Function: Target Engagement (Weapons Selection

Tasks	Pilot (%)	Copilot (%)
Decision of ordnance	5.0	-
Selection of ordnance	3.0	7.0
Final weapons system check	-	-

Function: Target Engagement (Method of Attack)

Tasks	Pilot (%)	Copilot (%)
Confirm method of attack	3.0	-
Attack angle	9.0	-
Aircraft trim	5.5	-
Aircraft track	12.5	-
Aircraft/target relationship	5.5	-

Function: Target Engagement (Weapons Control)

Tasks	Pilot (%)	Copilot (%)
Sight rockets	17.5	-
Fire rockets	11.0	-
Sight flex 7.62 MG	-	44.0
Fire flex 7.62 MG	-	13.5
Sight flex 40mm GL	-	11.0
Fire flex 40mm GL	-	7.0
Maneuver to disengage	12.5	-

Function: Communications (Internal)

Tasks	Pilot (%)	Copilot (%)
Final cockpit check	2.5	-
Weapons systems condition	3.0	-
Target identification statement	2.5	-
Ordnance delivery statement	4.0	2.5
Target information	2.5	-
Ammunition status	2.5	2.5
Aircraft status	4.0	1.5

Function: Communications (External)

Tasks	Pilot (%)	Copilot (%)
Air to air	5.0	-
Fire mission	2.5	-
Target information	4.0	-

Function: Countermeasures (Weapons)

Weapons control	-	2.5
Sight positioning	-	19.0
Maneuver	37.5	-

PHASE: OBJECTIVE SECURITY

Function: Vehicle Control (Manual)

Desired heading	15.5	-
Desired altitude	15.0	-
Desired airspeed	15.5	-
Dash to search/return	16.0	-
Terrain avoidance	-	-
Airborne object separation	-	-

Function: Navigation (Pilotage)

Refer to map	-	-
Refer to terrain	40	100

Function: Target Detection (Visual)

Search terrain	-	100

Function: Target Detection (Elec. Inst.)

Audio (Acoustic Detector)	-	-

Function: Communications (Internal)

Tasks	Pilot (%)	Copilot (%)
Position statement	-	8.0
Area to observe	7.0	-
Aircraft systems condition	-	-
Weapons systems condition	3.0	2.5

Function: Communications (External)

Air to air	14.0	-
Mission information	2.0	-
Artillery advisory	-	-

Function: Countermeasures

Maneuver	-	-
Weapons control	-	8.0
Sight positioning	-	100.0

PHASE: ESCORT OF COLUMN

Function: Vehicle Control

Desired heading	12.5	-
Desired altitude	8.0	-
Desired airspeed	2.5	-
Terrain avoidance	-	-
Airborne object separation	-	-

Function: Navigation (Pilotage)

Refer to map	9.5	33.5
Refer to terrain	9.0	18.5

Function: Navigation (Dead Reckoning)

Tasks	Pilot (%)	Copilot (%)
Compute heading	-	8.0
Compute time	-	10.0
Measure distance	-	10.0

Function: Navigation (Elect. Inst.)

Refer to ADF, VOR and/or FM	9.0	-

Function: Target Detection (Visual)

Search terrain	5.5	11.0

Function: Target Detection (Elect.)

Audio (Acoustic Detector)	-	-

Function: Communications (Internal)

Position statement	-	8.5
Area to observe	5.0	-
Aircraft systems condition	3.0	-
Weapons system condition	2.5	4.0

Function: Communications (External)

Air to air	6.5	-
Flight following/advisory	14.0	-

Function: IFF

Transponder On-Off	5.0	-
Altitude	4.0	-
Airspeed	2.5	-
Track	2.5	-

Function: Countermeasures

Tasks	Pilot (%)	Copilot (%)
Maneuver	9.0	-
Sight positioning	-	3.0

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APPENDIX C

UH-1C STUDY AIRCRAFT "PROTECTION NEED" MATRIX

This UH-1C pilot/copilot "protection need" matrix is based on the methods and procedures enumerated throughout Phase II of the Armored Systems Development Guideline.

Key:

Body Part	Number
Head	1
Thorax	2
Abdomen	3

The crew's arms and legs were not considered in this matrix because of their low hit-kill probabilities.

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Pilot

Direction of Fire		Crewman Body Part Number							
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4	40.5	42.4				
	315		38.4	40.5	42.4				
	292.5		38.4	40.5	42.4				
	270		38.4	40.5					
	247.5		38.4	40.5					
	225								
	202.5								
	180								
	157.5								
	135								
	112.5		38.4	40.5					
	90		38.4	40.5					
	67.5		38.4	40.5	42.4				
	45		38.4	40.5	42.4				
	22.5		38.4	40.5	42.4				
0	0		38.4	40.5	42.4				

Crewman: Copilot

EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4	40.5	42.4				
	315		38.4	40.5	42.4				
	292.5		38.4	40.5	42.4				
	270		38.4	40.5					
	247.5		38.4	40.5					
	225								
	202.5								
	180								
	157.5								
	135								
	112.5		38.4	40.5					
	90		38.4	40.5					
	67.5		38.4	40.5	42.4				
	45		38.4	40.5	42.4				
	22.5		38.4	40.5	42.4				
0	0		38.4	40.5	42.4				

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Pilot

Direction of Fire		Crewman Body Part Number							
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4	40.5	42.4				
	315		38.4	40.5	42.4				
	292.5		38.4	40.5	42.4				
	270		38.4	40.5	42.4				
	247.5		38.4	40.5					
	225		38.4						
	202.5		38.4						
+	180		38.4		42.4				
	157.5		38.4						
	135		38.4						
	112.5		38.4	40.5					
	90		38.4	40.5	42.4				
	67.5		38.4	40.5	42.4				
	45		38.4	40.5	42.4				
	22.5		38.4	40.5	42.4				
45	0		38.4	40.5	42.4				
	22.5		38.4	40.5					
	45		38.4	40.5					
	67.5		38.4	40.5					
	90		38.4	40.5					
	112.5		38.4	40.5					
	135		38.4						
	157.5		38.4						
−	180		38.4						
	202.5		38.4						
	225		38.4						
	247.5		38.4	40.5					
	270		38.4	40.5					
	292.5		38.4	40.5					
	315		38.4	40.5					
	337.5		38.4	40.5					

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Pilot

Direction of Fire		Crewman Body Part Number						
EL.	AZ.	1	2	3	4	5	6	7
	337.5	38.4	40.5	42.4				
	315	38.4	40.5	42.4				
	292.5	38.4	40.5	42.4				
	270	38.4	40.5					
	247.5	38.4	40.5					
	225	38.4						
	202.5	38.4						
+	180							
	157.5	38.4						
	135	38.4						
	112.5	38.4	40.5					
	90	38.4	40.5	42.4				
	67.5	38.4	40.5	42.4				
	45	38.4	40.5	42.4				
	22.5	38.4	40.5	42.4				
22.5	0	38.4	40.5	42.4				
	22.5	38.4	40.5	42.4				
	45	38.4	40.5	42.4				
	67.5	38.4	40.5	42.4				
	90	38.4	40.5					
	112.5	38.4						
	135							
	157.5							
−	180							
	202.5							
	225							
	247.5	38.4	40.5					
	270							
	292.5	38.4	40.5	42.4				
	315	38.4	40.5	42.4				
	337.5	38.4	40.5	42.4				

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Copilot

Direction of Fire		Crewman Body Part Number							
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4	40.5	42.4				
	315		38.4	40.5	42.4				
	292.5		38.4	40.5	42.4				
	270		38.4	40.5	42.4				
	247.5		38.4	40.5					
	225		38.4						
	202.5		38.4						
+	180								
	157.5		38.4						
	135		38.4						
	112.5		38.4	40.5					
	90		38.4	40.5					
	67.5		38.4	40.5	42.4				
	45		38.4	40.5	42.4				
	22.5		38.4	40.5	42.4				
22.5	0		38.4	40.5	42.4				
	22.5		38.4	40.5	42.4				
	45		38.4	40.5	42.4				
	67.5		38.4	40.5	42.4				
	90								
	112.5		38.4						
	135								
	157.5								
–	180								
	202.5								
	225								
	247.5		38.4	40.5					
	270		38.4	40.5					
	292.5		38.4	40.5	42.4				
	315		38.4	40.5	42.4				
	337.5		38.4	40.5	42.4				

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Copilot

Direction of Fire		Crewman Body Part Number						
EL.	AZ.	1	2	3	4	5	6	7
	337.5	38.4	40.5	42.4				
	315	38.4	40.5	42.4				
	292.5	38.4	40.5	42.4				
	270	38.4	40.5	42.4				
	247.5	38.4	40.5					
	225	38.4						
	202.5	38.4						
+	180	38.4		42.4				
	157.5	38.4						
	135	38.4						
	112.5	38.4	40.5					
	90	38.4	40.5	42.4				
	67.5	38.4	40.5	42.4				
	45	38.4	40.5	42.4				
	22.5	38.4	40.5	42.4				
45	0	38.4	40.5					
	22.5	38.4	40.5					
	45	38.4	40.5					
	67.5	38.4	40.5					
	90	38.4	40.5					
	112.5	38.4	40.5					
	135	38.4						
	157.5							
-	180							
	202.5							
	225	38.4						
	247.5	38.4	40.5					
	270	38.4	40.5					
	292.5	38.4	40.5					
	315	38.4	40.5					
	337.5	38.4	40.5					

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Pilot

Direction of Fire		Crewman Body Part Number							
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4	40.5					
	315		38.4	40.5					
	292.5		38.4	40.5					
	270		38.4	40.5					
	247.5		38.4	40.5					
	225		38.4	40.5					
	202.5		38.4						
+	180		38.4						
	157.5		38.4						
	135		38.4	40.5					
	112.5		38.4	40.5					
	90		38.4	40.5					
	67.5		38.4	40.5					
	45		38.4	40.5					
	22.5		38.4	40.5					
67.5	0		38.4	40.5					
	22.5								
	45			40.5					
	67.5			40.5					
	90		38.4	40.5					
	112.5			40.5					
	135		38.4						
	157.5		38.4						
-	180		38.4						
	202.5		38.4						
	225		38.4						
	247.5		38.4	40.5					
	270			40.5					
	292.5			40.5					
	315			40.5					
	337.5			40.5					

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Copilot

Direction of Fire		Crewman Body Part Number							
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	337.5		38.4	40.5					
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	292.5		38.4	40.5					
	270		38.4	40.5					
	247.5		38.4	40.5					
	225		38.4	40.5					
	202.5		38.4						
+	180		38.4						
	157.5		38.4						
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	112.5		38.4	40.5					
	90		38.4	40.5					
	67.5		38.4	40.5					
	45		38.4	40.5					
	22.5		38.4	40.5					
67.5	0		38.4	40.5					
	22.5								
	45			40.5					
	67.5			40.5					
	90		38.4	40.5					
	112.5			40.5					
	135		38.4						
	157.5		38.4						
−	180		38.4						
	202.5		38.4						
	225		38.4						
	247.5		38.4	40.5					
	270			40.5					
	292.5			40.5					
	315			40.5					
	337.5			40.5					

AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Pilot

Direction of Fire			Crewman Body Part Number						
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4						
	315		38.4						
	292.5		38.4						
	270		38.4						
	247.5		38.4						
	225		38.4						
	202.5		38.4						
+	180		38.4						
	157.5		38.4						
	135		38.4						
	112.5		38.4						
	90		38.4						
	67.5		38.4						
	45		38.4						
	22.5		38.4						
90	0		38.4	40.5					
	22.5								
	45								
	67.5								
	90								
	112.5								
	135								
	157.5								
—	180								
	202.5								
	225								
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	292.5								
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AIRCREW "PROTECTION NEED" MATRIX

Aircraft: UH-1C
Crewman: Copilot

Direction of Fire		Crewman Body Part Number							
EL.	AZ.		1	2	3	4	5	6	7
	337.5		38.4						
	315		38.4						
	292.5		38.4						
	270		38.4						
	247.5		38.4						
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	202.5		38.4						
+	180		38.4						
	157.5		38.4						
	135		38.4						
	112.5		38.4						
	90		38.4						
	67.5		38.4						
	45		38.4						
	22.5		38.4						
90	0				42.4				
	22.5								
	45								
	67.5								
	90								
	112.5								
	135								
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	337.5								

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13. ABSTRACT

This guide was developed to establish a systematic approach to the design of aircrew armor systems. It provides an integrated investigation of the feasibility of adding armor to an aircraft based on the aircraft's systems, mission and performance requirements; and the assessment of the aircrew's "protection need" based on the aircraft's mission, environment, required aircrew functions, and inherent ballistic protection provided the crew by the aircraft components.

The data derived from these analyses are synthesized into an Armor Design/Evaluation Methodology which utilizes a complex computer-graphics technique as a design tool. To illustrate this computer technique, several sample armor configurations modeled on the UH-1C aircraft are developed and evaluated. The effectiveness of this method, however, depends upon the accuracy of the input data generated and upon the application of human factors design principles.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Human Factors Engineering						
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